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# *PVT* Measurements, Virial Coefficients, and Joule-Thomson Inversion Curve of Fluorine*

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**(June 1, 1970)**

Experimental *PVT* measurements on gaseous and liquid fluorine from the triple point (53.5 K) to 300 K at pressures to about 21 MN/m² are presented. The data are represented by a truncated virial equation in the low-density region. Comparisons of the second virial coefficient from this equation are made with published data. The *PVT* relationship along the Joule-Thomson inversion curve was obtained from the isotherm-isochore representation of the high density region.

Key words: Isochores; isotherms; Joule-Thomson inversion curve; liquid densities along melting line; PVT data; second virial coefficient; third virial coefficient.

## 1. Introduction

This laboratory is currently engaged in a comprehensive program to determine the thermodynamic and transport properties of compressed liquid and gaseous fluorine. Extensive, precise, *PVT* data are essential to the calculation of thermodynamic functions required for engineering development of proposed rocket propulsion systems. Since fluorine is not only the most reactive of all elements but also extremely toxic, it is not surprising that physical properties data on this fluid have either been inconsistent or, in many cases, nonexistent. Recently, however, some thermodynamic data have been reported by the authors of this paper [1, 2, 3].[1] The equations representing these data are given in the appendix of this paper for the sake of completeness.

It is the purpose of this paper to report new experimental *PVT* data from the triple point (53.5 K) to 300 K for pressures to a maximum of 21 MN/m² (1 MN/m² = 9.86923 atm). Also reported are derived values for the second and third virial coefficients and the Joule-Thomson inversion curve.

## 2. *PVT* Measurements

The experimental apparatus and instrumentation used for the *PVT* measurements on fluorine have been described earlier [4]. To measure single-phase densities, the common gas expansion method was used. After filling and closing off the sample holder, a sequence of pressure-temperature observations were made on the nearly constant density fluid confined in the *PVT* cell whose volume was accurately calibrated. Temperatures were regulated at integral values (on IPTS 1948 and the NBS 1955 temperature scale) to permit analysis of the data along isotherms. The temperatures of table 1, however, were converted to IPTS 1968 using the temperature scale differences given by references [5, 6]. When either maximum pressure (21 MN/m²) or maximum temperature (300 K) was reached, the fluorine sample in the *PVT* cell was expanded into large calibrated volumes maintained near room temperature. The density could then be determined since the volume of the sample holder and the compressibility factor, $PV/RT$, of fluorine gas at the conditions in the expansion volumes were known. This fluorine compressibility factor was obtained using Burnett [7] gas expansion techniques. The results of all volume calibrations necessary for the density determination and the Burnett expansion experiment may be obtained from reference [8].

All experimental single-phase *PVT* data in both the compressed liquid and vapor regions are given in table 1. The column of this table labeled "IDENT" contains the identification number of each data point. The last two digits represent the point number while the remaining digits are the number of the run or experimental isochore. Entries in runs 120 and 121 which contain no value for the density are pressures measured on the melting curve. Experimental *PVT* data for densities less than 0.22 mol/l were obtained indirectly, since gas expansion measurements at these low densities were not possible. Pressures were obtained using an air deadweight gage while the density was obtained by heating the *PVT* cell to 175 K using an extrapolation of the previously determined pressure-density relationship for that isotherm obtained from higher density measurements.

*This work was carried out at the National Bureau of Standards under the sponsorship of the United States Air Force (MIPR No. FO 4611-70-X-0001).
**Cryogenics Division, National Bureau of Standards Laboratories, Boulder, Colo. 80302.
[1] Figures in brackets indicate the literature references at the end of this paper.

TABLE 1 . TEMPERATURE-PRESSURE-DENSITY OBSERVATIONS ON FLUORINE

| TEMP K | PRESSURE MN/M$^2$ | DENSITY MOL/L | IDENT |
|---|---|---|---|
| 74.994 | 0.0231 | 0.0379 | 13101 |
| 79.991 | 0.0249 | 0.0378 | 13102 |
| 84.997 | 0.0265 | 0.0378 | 13103 |
| 90.010 | 0.0280 | 0.0378 | 13104 |
| 95.013 | 0.0296 | 0.0378 | 13105 |
| 100.010 | 0.0312 | 0.0378 | 13106 |
| 109.998 | 0.0343 | 0.0377 | 13107 |
| 119.989 | 0.0374 | 0.0377 | 13108 |
| 129.987 | 0.0405 | 0.0377 | 13109 |
| 139.992 | 0.0436 | 0.0376 | 13110 |
| 79.991 | 0.0479 | 0.0740 | 13001 |
| 84.997 | 0.0513 | 0.0739 | 13002 |
| 90.010 | 0.0544 | 0.0739 | 13003 |
| 95.013 | 0.0575 | 0.0738 | 13004 |
| 100.010 | 0.0606 | 0.0738 | 13005 |
| 109.998 | 0.0667 | 0.0737 | 13006 |
| 119.989 | 0.0729 | 0.0737 | 13007 |
| 129.987 | 0.0789 | 0.0736 | 13008 |
| 139.992 | 0.0850 | 0.0735 | 13009 |
| 84.997 | 0.0955 | 0.1403 | 12901 |
| 90.010 | 0.1020 | 0.1403 | 12902 |
| 95.013 | 0.1080 | 0.1402 | 12903 |
| 100.010 | 0.1139 | 0.1401 | 12904 |
| 105.004 | 0.1198 | 0.1401 | 12905 |
| 119.989 | 0.1373 | 0.1398 | 12906 |
| 129.987 | 0.1489 | 0.1397 | 12907 |
| 139.992 | 0.1605 | 0.1396 | 12908 |
| 90.010 | 0.1516 | 0.2118 | 12801 |
| 95.013 | 0.1609 | 0.2117 | 12802 |
| 100.010 | 0.1699 | 0.2116 | 12803 |
| 105.004 | 0.1789 | 0.2115 | 12804 |
| 109.998 | 0.1879 | 0.2114 | 12805 |
| 119.989 | 0.2057 | 0.2111 | 12806 |
| 129.987 | 0.2234 | 0.2109 | 12807 |
| 139.992 | 0.2410 | 0.2107 | 12808 |
| 95.013 | 0.2640 | 0.3576 | 12301 |
| 100.010 | 0.2803 | 0.3574 | 12302 |
| 109.998 | 0.3112 | 0.3571 | 12303 |
| 119.989 | 0.3417 | 0.3567 | 12304 |
| 129.987 | 0.3721 | 0.3563 | 12305 |
| 139.992 | 0.4022 | 0.3559 | 12306 |
| 102.008 | 0.4305 | 0.5538 | 12701 |
| 105.004 | 0.4454 | 0.5537 | 12702 |
| 109.998 | 0.4699 | 0.5534 | 12703 |
| 114.994 | 0.4942 | 0.5531 | 12704 |
| 119.989 | 0.5183 | 0.5528 | 12705 |
| 129.987 | 0.5661 | 0.5522 | 12706 |
| 139.992 | 0.6136 | 0.5516 | 12707 |
| 105.004 | 0.6031 | 0.7767 | 12501 |
| 109.998 | 0.6390 | 0.7763 | 12502 |
| 114.994 | 0.6740 | 0.7759 | 12503 |
| 119.989 | 0.7086 | 0.7755 | 12504 |
| 124.987 | 0.7430 | 0.7751 | 12505 |
| 129.987 | 0.7772 | 0.7746 | 12506 |
| 139.992 | 0.8451 | 0.7738 | 12507 |
| 111.996 | 0.9141 | 1.1436 | 12402 |
| 114.994 | 0.9465 | 1.1432 | 12403 |
| 119.989 | 0.9997 | 1.1426 | 12404 |
| 129.987 | 1.1044 | 1.1413 | 12405 |
| 139.992 | 1.2075 | 1.1400 | 12406 |
| 115.993 | 1.2050 | 1.5135 | 8101 |
| 117.991 | 1.2348 | 1.5132 | 8102 |
| 119.989 | 1.2641 | 1.5128 | 8103 |
| 121.988 | 1.2932 | 1.5125 | 8104 |
| 123.987 | 1.3221 | 1.5121 | 8105 |
| 125.987 | 1.3510 | 1.5118 | 8106 |
| 127.987 | 1.3794 | 1.5114 | 8107 |
| 129.987 | 1.4080 | 1.5111 | 8108 |
| 131.987 | 1.4363 | 1.5107 | 8109 |
| 133.988 | 1.4645 | 1.5104 | 8110 |
| 135.989 | 1.4925 | 1.5101 | 8111 |
| 137.990 | 1.5206 | 1.5097 | 8112 |
| 139.992 | 1.5486 | 1.5094 | 8113 |
| 141.993 | 1.5765 | 1.5090 | 8114 |
| 143.995 | 1.6042 | 1.5087 | 8115 |
| 145.996 | 1.6319 | 1.5083 | 8116 |
| 147.998 | 1.6596 | 1.5080 | 8117 |
| 150.000 | 1.6871 | 1.5077 | 8118 |
| 155.005 | 1.7556 | 1.5068 | 8119 |
| 160.010 | 1.8237 | 1.5059 | 8120 |
| 165.014 | 1.8916 | 1.5051 | 8121 |
| 170.019 | 1.9592 | 1.5042 | 8122 |
| 175.024 | 2.0264 | 1.5033 | 8123 |
| 180.027 | 2.0936 | 1.5025 | 8124 |
| 185.030 | 2.1603 | 1.5016 | 8125 |
| 190.032 | 2.2268 | 1.5007 | 8126 |
| 195.034 | 2.2931 | 1.4998 | 8127 |
| 200.035 | 2.3592 | 1.4990 | 8128 |
| 210.033 | 2.4909 | 1.4972 | 8129 |
| 220.030 | 2.6218 | 1.4954 | 8130 |
| 220.030 | 2.6214 | 1.4954 | 8131 |
| 230.025 | 2.7517 | 1.4935 | 8132 |
| 240.020 | 2.8812 | 1.4917 | 8133 |
| 250.014 | 3.0103 | 1.4898 | 8134 |
| 260.008 | 3.1389 | 1.4880 | 8135 |
| 270.002 | 3.2670 | 1.4861 | 8136 |
| 279.997 | 3.3946 | 1.4842 | 8137 |
| 289.994 | 3.5216 | 1.4822 | 8138 |
| 299.992 | 3.6484 | 1.4803 | 8139 |
| 121.988 | 1.6805 | 2.1162 | 12601 |
| 124.987 | 1.7449 | 2.1154 | 12602 |
| 129.987 | 1.8504 | 2.1141 | 12603 |
| 134.988 | 1.9543 | 2.1129 | 12604 |
| 139.992 | 2.0568 | 2.1116 | 12605 |
| 144.995 | 2.1583 | 2.1104 | 12606 |
| 150.000 | 2.2589 | 2.1091 | 12607 |
| 125.987 | 2.0758 | 2.6479 | 7401 |
| 127.987 | 2.1314 | 2.6472 | 7402 |
| 129.987 | 2.1865 | 2.6466 | 7403 |
| 131.987 | 2.2411 | 2.6459 | 7404 |
| 133.988 | 2.2954 | 2.6453 | 7405 |
| 135.989 | 2.3491 | 2.6446 | 7406 |
| 137.990 | 2.4026 | 2.6440 | 7407 |
| 139.992 | 2.4558 | 2.6433 | 7408 |
| 141.993 | 2.5088 | 2.6427 | 7409 |
| 143.995 | 2.5614 | 2.6420 | 7410 |
| 145.996 | 2.6138 | 2.6414 | 7411 |
| 147.998 | 2.6659 | 2.6407 | 7412 |
| 150.000 | 2.7180 | 2.6401 | 7413 |
| 155.005 | 2.8470 | 2.6384 | 7414 |
| 160.010 | 2.9751 | 2.6368 | 7415 |
| 165.014 | 3.1021 | 2.6352 | 7416 |
| 170.019 | 3.2284 | 2.6336 | 7417 |
| 175.024 | 3.3538 | 2.6319 | 7418 |
| 180.027 | 3.4784 | 2.6303 | 7419 |
| 185.030 | 3.6024 | 2.6287 | 7420 |
| 190.032 | 3.7260 | 2.6270 | 7421 |
| 195.034 | 3.8486 | 2.6254 | 7422 |

TABLE 1 . TEMPERATURE-PRESSURE-DENSITY OBSERVATIONS ON FLUORINE--CONTINUED

| TEMP K | PRESSURE MN/M$^2$ | DENSITY MOL/L | IDENT |
|---|---|---|---|
| 195.034 | 3.8486 | 2.6254 | 7422 |
| 200.035 | 3.9711 | 2.6238 | 7423 |
| 210.033 | 4.2145 | 2.6204 | 7424 |
| 220.030 | 4.4562 | 2.6171 | 7425 |
| 230.025 | 4.6964 | 2.6138 | 7426 |
| 240.020 | 4.9347 | 2.6104 | 7427 |
| 230.025 | 4.6968 | 2.6140 | 7428 |
| 240.020 | 4.9356 | 2.6106 | 7429 |
| 250.014 | 5.1732 | 2.6072 | 7430 |
| 260.008 | 5.4093 | 2.6038 | 7431 |
| 270.002 | 5.6446 | 2.6004 | 7432 |
| 279.997 | 5.8785 | 2.5969 | 7433 |
| 289.994 | 6.1114 | 2.5933 | 7434 |
| 299.992 | 6.3432 | 2.5897 | 7435 |
| | | | |
| 129.987 | 2.6958 | 3.6637 | 7201 |
| 131.987 | 2.7788 | 3.6627 | 7202 |
| 133.988 | 2.8604 | 3.6617 | 7203 |
| 135.989 | 2.9410 | 3.6608 | 7204 |
| 137.990 | 3.0209 | 3.6598 | 7205 |
| 139.992 | 3.1001 | 3.6588 | 7206 |
| 141.993 | 3.1786 | 3.6579 | 7207 |
| 143.995 | 3.2565 | 3.6569 | 7208 |
| 145.996 | 3.3341 | 3.6560 | 7209 |
| 147.998 | 3.4110 | 3.6550 | 7210 |
| 150.000 | 3.4876 | 3.6540 | 7211 |
| 155.005 | 3.6773 | 3.6517 | 7212 |
| 160.010 | 3.8649 | 3.6493 | 7213 |
| 165.014 | 4.0507 | 3.6470 | 7214 |
| 170.019 | 4.2350 | 3.6446 | 7215 |
| 175.024 | 4.4179 | 3.6423 | 7216 |
| 180.027 | 4.5994 | 3.6399 | 7217 |
| 180.027 | 4.5995 | 3.6401 | 7218 |
| 185.030 | 4.7802 | 3.6378 | 7219 |
| 190.032 | 4.9597 | 3.6354 | 7220 |
| 195.034 | 5.1383 | 3.6330 | 7221 |
| 200.035 | 5.3160 | 3.6307 | 7222 |
| 210.033 | 5.6689 | 3.6259 | 7223 |
| 220.030 | 6.0188 | 3.6211 | 7224 |
| 230.025 | 6.3662 | 3.6163 | 7225 |
| 240.020 | 6.7110 | 3.6114 | 7226 |
| 250.014 | 7.0537 | 3.6065 | 7227 |
| 260.008 | 7.3946 | 3.6015 | 7228 |
| 270.002 | 7.7335 | 3.5966 | 7229 |
| 279.997 | 8.0706 | 3.5915 | 7230 |
| 289.994 | 8.4063 | 3.5865 | 7231 |
| 299.992 | 8.7404 | 3.5813 | 7232 |
| | | | |
| 150.000 | 3.9137 | 4.3084 | 8501 |
| 165.014 | 4.6013 | 4.2998 | 8502 |
| 180.027 | 5.2692 | 4.2913 | 8503 |
| 200.035 | 6.1393 | 4.2799 | 8504 |
| 230.025 | 7.4114 | 4.2626 | 8505 |
| | | | |
| 133.988 | 3.2925 | 4.7443 | 7001 |
| 135.989 | 3.4060 | 4.7430 | 7002 |
| 137.990 | 3.5176 | 4.7416 | 7003 |
| 139.992 | 3.6277 | 4.7403 | 7004 |
| 141.993 | 3.7366 | 4.7389 | 7005 |
| 143.995 | 3.8445 | 4.7376 | 7006 |
| 145.996 | 3.9514 | 4.7363 | 7007 |
| 147.998 | 4.0575 | 4.7350 | 7008 |
| 150.000 | 4.1629 | 4.7337 | 7009 |
| 155.005 | 4.4233 | 4.7304 | 7010 |
| 160.010 | 4.6804 | 4.7272 | 7011 |
| 165.014 | 4.9344 | 4.7240 | 7012 |
| 170.019 | 5.1861 | 4.7208 | 7013 |
| 175.024 | 5.4345 | 4.7176 | 7014 |
| 180.027 | 5.6819 | 4.7144 | 7015 |
| 185.030 | 5.9278 | 4.7113 | 7016 |
| 190.032 | 6.1719 | 4.7081 | 7017 |
| 195.034 | 6.4144 | 4.7049 | 7018 |
| 200.035 | 6.6558 | 4.7018 | 7019 |
| 210.033 | 7.1347 | 4.6954 | 7020 |
| 220.030 | 7.6091 | 4.6890 | 7021 |
| 210.033 | 7.1344 | 4.6952 | 7022 |
| 220.030 | 7.6091 | 4.6888 | 7023 |
| 230.025 | 8.0796 | 4.6824 | 7024 |
| 240.020 | 8.5464 | 4.6759 | 7025 |
| 250.014 | 9.0103 | 4.6693 | 7026 |
| 260.008 | 9.4713 | 4.6627 | 7027 |
| 270.002 | 9.9295 | 4.6560 | 7028 |
| 279.997 | 10.3848 | 4.6493 | 7029 |
| 289.994 | 10.8367 | 4.6425 | 7030 |
| 299.992 | 11.2872 | 4.6357 | 7031 |
| | | | |
| 137.990 | 3.7717 | 5.4871 | 8301 |
| 139.992 | 3.9057 | 5.4855 | 8302 |
| 141.993 | 4.0376 | 5.4839 | 8303 |
| 143.995 | 4.1679 | 5.4823 | 8304 |
| 145.996 | 4.2969 | 5.4808 | 8305 |
| 147.998 | 4.4249 | 5.4792 | 8306 |
| 150.000 | 4.5515 | 5.4776 | 8307 |
| 155.005 | 4.8645 | 5.4737 | 8308 |
| 160.010 | 5.1727 | 5.4699 | 8309 |
| 165.014 | 5.4770 | 5.4660 | 8310 |
| 170.019 | 5.7784 | 5.4622 | 8311 |
| 175.024 | 6.0765 | 5.4585 | 8312 |
| 180.027 | 6.3724 | 5.4547 | 8313 |
| 185.030 | 6.6661 | 5.4509 | 8314 |
| 190.032 | 6.9578 | 5.4471 | 8315 |
| 195.034 | 7.2477 | 5.4433 | 8316 |
| 200.035 | 7.5357 | 5.4395 | 8317 |
| 210.033 | 8.1071 | 5.4319 | 8318 |
| 220.030 | 8.6730 | 5.4242 | 8319 |
| 220.030 | 8.6715 | 5.4241 | 8320 |
| 230.025 | 9.2328 | 5.4165 | 8321 |
| 240.020 | 9.7891 | 5.4087 | 8322 |
| 250.014 | 10.3417 | 5.4008 | 8323 |
| 260.008 | 10.8902 | 5.3929 | 8324 |
| 270.002 | 11.4359 | 5.3849 | 8325 |
| 279.997 | 11.9776 | 5.3769 | 8326 |
| 289.994 | 12.5164 | 5.3687 | 8327 |
| 299.992 | 13.0526 | 5.3605 | 8328 |
| | | | |
| 137.990 | 3.9283 | 6.0824 | 6901 |
| 139.992 | 4.0827 | 6.0805 | 6902 |
| 141.993 | 4.2341 | 6.0787 | 6903 |
| 143.995 | 4.3832 | 6.0769 | 6904 |
| 145.996 | 4.5308 | 6.0751 | 6905 |
| 147.998 | 4.6767 | 6.0733 | 6906 |
| 150.000 | 4.8213 | 6.0715 | 6907 |
| 155.005 | 5.1779 | 6.0671 | 6908 |
| 160.010 | 5.5288 | 6.0627 | 6909 |
| 165.014 | 5.8752 | 6.0583 | 6910 |
| 170.019 | 6.2174 | 6.0540 | 6911 |
| 175.024 | 6.5565 | 6.0496 | 6912 |
| 180.027 | 6.8924 | 6.0453 | 6913 |
| 185.030 | 7.2260 | 6.0410 | 6914 |
| 190.032 | 7.5572 | 6.0366 | 6915 |
| 195.034 | 7.8860 | 6.0323 | 6916 |

TABLE 1 . TEMPERATURE-PRESSURE-DENSITY OBSERVATIONS ON FLUORINE--CONTINUED

| TEMP K | PRESSURE MN/M$^2$ | DENSITY MOL/L | IDENT | TEMP K | PRESSURE MN/M$^2$ | DENSITY MOL/L | IDENT |
|---|---|---|---|---|---|---|---|
| 200.035 | 8.2131 | 6.0279 | 6917 | 289.994 | 15.6802 | 6.7219 | 2727 |
| 210.033 | 8.8617 | 6.0192 | 6918 | 299.992 | 16.3876 | 6.7111 | 2728 |
| 220.030 | 9.5038 | 6.0105 | 6919 | | | | |
| 230.025 | 10.1405 | 6.0017 | 6920 | | | | |
| 240.020 | 10.7703 | 5.9929 | 6921 | 141.993 | 4.5958 | 7.6840 | 7501 |
| 250.014 | 11.3966 | 5.9841 | 6922 | 143.995 | 4.8006 | 7.6815 | 7502 |
| 260.008 | 12.0190 | 5.9751 | 6923 | 145.996 | 5.0015 | 7.6791 | 7503 |
| 270.002 | 12.6373 | 5.9662 | 6924 | 147.998 | 5.2001 | 7.6767 | 7504 |
| 279.997 | 13.2518 | 5.9571 | 6925 | 150.000 | 5.3960 | 7.6743 | 7505 |
| 289.994 | 13.8633 | 5.9479 | 6926 | 155.005 | 5.8780 | 7.6683 | 7506 |
| 299.992 | 14.4706 | 5.9387 | 6927 | 160.010 | 6.3513 | 7.6624 | 7507 |
| | | | | 165.014 | 6.8179 | 7.6565 | 7508 |
| | | | | 170.019 | 7.2790 | 7.6507 | 7509 |
| 139.992 | 4.2052 | 6.5928 | 7801 | 175.024 | 7.7353 | 7.6449 | 7510 |
| 141.993 | 4.3745 | 6.5908 | 7802 | 180.027 | 8.1862 | 7.6392 | 7511 |
| 143.995 | 4.5407 | 6.5888 | 7803 | 185.030 | 8.6352 | 7.6334 | 7512 |
| 145.996 | 4.7050 | 6.5868 | 7804 | 190.032 | 9.0807 | 7.6276 | 7513 |
| 147.998 | 4.8670 | 6.5848 | 7805 | 190.032 | 9.0802 | 7.6275 | 7514 |
| 150.000 | 5.0275 | 6.5828 | 7806 | 195.034 | 9.5228 | 7.6217 | 7515 |
| 155.005 | 5.4232 | 6.5779 | 7807 | 200.035 | 9.9626 | 7.6159 | 7516 |
| 160.010 | 5.8120 | 6.5730 | 7808 | 210.033 | 10.8353 | 7.6043 | 7517 |
| 165.014 | 6.1955 | 6.5681 | 7809 | 220.030 | 11.6987 | 7.5926 | 7518 |
| 170.019 | 6.5732 | 6.5633 | 7810 | 230.025 | 12.5549 | 7.5808 | 7519 |
| 175.024 | 6.9484 | 6.5586 | 7811 | 240.020 | 13.4022 | 7.5689 | 7520 |
| 180.027 | 7.3206 | 6.5538 | 7812 | 250.014 | 14.2444 | 7.5570 | 7521 |
| 185.030 | 7.6898 | 6.5490 | 7813 | 260.008 | 15.0797 | 7.5449 | 7522 |
| 190.032 | 8.0560 | 6.5442 | 7814 | 270.002 | 15.9091 | 7.5327 | 7523 |
| 195.034 | 8.4200 | 6.5395 | 7815 | 279.997 | 16.7342 | 7.5203 | 7524 |
| 200.035 | 8.7819 | 6.5346 | 7816 | 289.994 | 17.5523 | 7.5078 | 7525 |
| 210.033 | 9.4992 | 6.5251 | 7817 | 299.992 | 18.3667 | 7.4953 | 7526 |
| 220.030 | 10.2098 | 6.5154 | 7818 | | | | |
| 230.025 | 10.9136 | 6.5058 | 7819 | | | | |
| 230.025 | 10.9148 | 6.5061 | 7820 | | | | |
| 240.020 | 11.6123 | 6.4962 | 7821 | 185.030 | 8.9694 | 8.0302 | 8401 |
| 250.014 | 12.3046 | 6.4862 | 7822 | 195.034 | 9.9172 | 8.0179 | 8402 |
| 260.008 | 12.9920 | 6.4762 | 7823 | 210.033 | 11.3172 | 7.9994 | 8403 |
| 270.002 | 13.6750 | 6.4661 | 7824 | 230.025 | 13.1530 | 7.9743 | 8404 |
| 279.997 | 14.3536 | 6.4559 | 7825 | | | | |
| 289.994 | 15.0284 | 6.4456 | 7826 | | | | |
| 299.992 | 15.6989 | 6.4353 | 7827 | 143.995 | 4.9168 | 8.3819 | 11901 |
| | | | | 145.996 | 5.1430 | 8.3791 | 11902 |
| | | | | 147.998 | 5.3652 | 8.3764 | 11903 |
| 139.992 | 4.2620 | 6.8747 | 2701 | 150.000 | 5.5847 | 8.3737 | 11904 |
| 141.993 | 4.4415 | 6.8725 | 2702 | 155.005 | 6.1242 | 8.3671 | 11905 |
| 143.995 | 4.6175 | 6.8704 | 2703 | 160.010 | 6.6540 | 8.3605 | 11906 |
| 145.996 | 4.7909 | 6.8683 | 2704 | 165.014 | 7.1759 | 8.3539 | 11907 |
| 147.998 | 4.9623 | 6.8662 | 2705 | 170.019 | 7.6922 | 8.3474 | 11908 |
| 150.000 | 5.1318 | 6.8642 | 2706 | 175.024 | 8.2027 | 8.3409 | 11909 |
| 155.005 | 5.5490 | 6.8590 | 2707 | 180.027 | 8.7093 | 8.3345 | 11910 |
| 160.010 | 5.9593 | 6.8540 | 2708 | 185.030 | 9.2117 | 8.3280 | 11911 |
| 165.014 | 6.3637 | 6.8489 | 2709 | 190.032 | 9.7107 | 8.3215 | 11912 |
| 170.019 | 6.7637 | 6.8439 | 2710 | 195.034 | 10.2065 | 8.3150 | 11913 |
| 175.024 | 7.1593 | 6.8389 | 2711 | 200.035 | 10.6993 | 8.3085 | 11914 |
| 180.027 | 7.5515 | 6.8339 | 2712 | 210.033 | 11.6772 | 8.2955 | 11915 |
| 185.030 | 7.9406 | 6.8290 | 2713 | 220.030 | 12.6444 | 8.2825 | 11916 |
| 190.032 | 8.3270 | 6.8240 | 2714 | 210.033 | 11.6741 | 8.2952 | 11917 |
| 195.034 | 8.7109 | 6.8190 | 2715 | 220.030 | 12.6416 | 8.2821 | 11918 |
| 200.035 | 9.0924 | 6.8140 | 2716 | 230.025 | 13.5995 | 8.2689 | 11919 |
| 210.033 | 9.8489 | 6.8040 | 2717 | 240.020 | 14.5502 | 8.2556 | 11920 |
| 220.030 | 10.5977 | 6.7940 | 2718 | 250.014 | 15.4923 | 8.2422 | 11921 |
| 230.025 | 11.3398 | 6.7839 | 2719 | 260.008 | 16.4281 | 8.2287 | 11922 |
| 220.030 | 10.5990 | 6.7943 | 2720 | 270.002 | 17.3573 | 8.2151 | 11923 |
| 230.025 | 11.3409 | 6.7842 | 2721 | 279.997 | 18.2803 | 8.2013 | 11924 |
| 240.020 | 12.0771 | 6.7740 | 2722 | 289.994 | 19.1973 | 8.1874 | 11925 |
| 250.014 | 12.8074 | 6.7638 | 2723 | 299.992 | 20.1092 | 8.1732 | 11926 |
| 260.008 | 13.5329 | 6.7535 | 2724 | | | | |
| 270.002 | 14.2532 | 6.7430 | 2725 | | | | |
| 279.997 | 14.9689 | 6.7325 | 2726 | 141.993 | 4.7140 | 8.7499 | 3102 |

TABLE 1 . TEMPERATURE-PRESSURE-DENSITY OBSERVATIONS ON FLUORINE--CONTINUED

| TEMP K | PRESSURE MN/M$^2$ | DENSITY MOL/L | IDENT | TEMP K | PRESSURE MN/M$^2$ | DENSITY MOL/L | IDENT |
|---|---|---|---|---|---|---|---|
| 143.995 | 4.9677 | 8.7468 | 3103 | 200.035 | 12.1356 | 9.6809 | 7614 |
| 145.996 | 5.2069 | 8.7439 | 3104 | 210.033 | 13.3343 | 9.6649 | 7615 |
| 147.998 | 5.4421 | 8.7411 | 3105 | 220.030 | 14.5208 | 9.6488 | 7616 |
| 150.000 | 5.6739 | 8.7382 | 3106 | 230.025 | 15.6937 | 9.6326 | 7617 |
| 155.005 | 6.2440 | 8.7312 | 3107 | 230.025 | 15.6950 | 9.6329 | 7618 |
| 160.010 | 6.8033 | 8.7243 | 3108 | 240.020 | 16.8613 | 9.6166 | 7619 |
| 165.014 | 7.3548 | 8.7174 | 3109 | 250.014 | 18.0166 | 9.6000 | 7620 |
| 170.019 | 7.9002 | 8.7105 | 3110 | 260.008 | 19.1645 | 9.5833 | 7621 |
| 175.024 | 8.4399 | 8.7037 | 3111 | 270.002 | 20.3049 | 9.5663 | 7622 |
| 180.027 | 8.9755 | 8.6969 | 3112 | | | | |
| 185.030 | 9.5067 | 8.6901 | 3113 | | | | |
| 190.032 | 10.0342 | 8.6833 | 3114 | 143.995 | 5.1231 | 10.8686 | 8001 |
| 195.034 | 10.5584 | 8.6765 | 3115 | 145.996 | 5.4415 | 10.8647 | 8002 |
| 200.035 | 11.0798 | 8.6697 | 3116 | 147.998 | 5.7518 | 10.8608 | 8003 |
| 210.033 | 12.1133 | 8.6560 | 3117 | 150.000 | 6.0578 | 10.8570 | 8004 |
| 220.030 | 13.1363 | 8.6423 | 3118 | 155.005 | 6.8106 | 10.8477 | 8005 |
| 220.030 | 13.1341 | 8.6416 | 3119 | 160.010 | 7.5519 | 10.8384 | 8006 |
| 230.025 | 14.1478 | 8.6278 | 3120 | 165.014 | 8.2847 | 10.8291 | 8007 |
| 240.020 | 15.1530 | 8.6140 | 3121 | 170.019 | 9.0106 | 10.8199 | 8008 |
| 250.014 | 16.1502 | 8.6000 | 3122 | 175.024 | 9.7306 | 10.8108 | 8009 |
| 260.008 | 17.1403 | 8.5859 | 3123 | 180.027 | 10.4459 | 10.8016 | 8010 |
| 270.002 | 18.1231 | 8.5717 | 3124 | 185.030 | 11.1567 | 10.7925 | 8011 |
| 279.997 | 19.0990 | 8.5572 | 3125 | 190.032 | 11.8630 | 10.7834 | 8012 |
| 289.994 | 20.0680 | 8.5426 | 3126 | 195.034 | 12.5659 | 10.7742 | 8013 |
| 299.992 | 21.0320 | 8.5278 | 3127 | 200.035 | 13.2650 | 10.7650 | 8014 |
| | | | | 210.033 | 14.6522 | 10.7466 | 8015 |
| | | | | 220.030 | 16.0262 | 10.7279 | 8016 |
| 143.995 | 4.9995 | 9.0187 | 8201 | 230.025 | 17.3881 | 10.7092 | 8017 |
| 145.996 | 5.2489 | 9.0157 | 8202 | 240.020 | 18.7385 | 10.6903 | 8018 |
| 147.998 | 5.4935 | 9.0127 | 8203 | 250.014 | 20.0784 | 10.6712 | 8019 |
| 150.000 | 5.7349 | 9.0097 | 8204 | 260.008 | 21.4083 | 10.6519 | 8020 |
| 155.005 | 6.3276 | 9.0024 | 8205 | | | | |
| 160.010 | 6.9099 | 8.9953 | 8206 | | | | |
| 165.014 | 7.4838 | 8.9881 | 8207 | 145.996 | 5.5018 | 11.9244 | 7902 |
| 170.019 | 8.0512 | 8.9809 | 8208 | 147.998 | 5.8491 | 11.9201 | 7903 |
| 175.024 | 8.6132 | 8.9738 | 8209 | 150.000 | 6.1922 | 11.9159 | 7904 |
| 180.027 | 9.1705 | 8.9667 | 8210 | 155.005 | 7.0392 | 11.9053 | 7905 |
| 185.030 | 9.7235 | 8.9596 | 8211 | 160.010 | 7.8758 | 11.8948 | 7906 |
| 190.032 | 10.2729 | 8.9524 | 8212 | 165.014 | 8.7053 | 11.8843 | 7907 |
| 195.034 | 10.8190 | 8.9453 | 8213 | 170.019 | 9.5289 | 11.8739 | 7908 |
| 200.035 | 11.3619 | 8.9381 | 8214 | 175.024 | 10.3471 | 11.8634 | 7909 |
| 143.995 | 4.9977 | 9.0186 | 8215 | 180.027 | 11.1599 | 11.8530 | 7910 |
| 170.019 | 8.0504 | 8.9805 | 8216 | 185.030 | 11.9686 | 11.8425 | 7911 |
| 200.035 | 11.3610 | 8.9378 | 8217 | 190.032 | 12.7733 | 11.8321 | 7912 |
| 210.033 | 12.4354 | 8.9234 | 8218 | 195.034 | 13.5742 | 11.8216 | 7913 |
| 220.030 | 13.5009 | 8.9090 | 8219 | 200.035 | 14.3705 | 11.8111 | 7914 |
| 230.025 | 14.5573 | 8.8945 | 8220 | 210.033 | 15.9527 | 11.7900 | 7915 |
| 240.020 | 15.6029 | 8.8798 | 8221 | 220.030 | 17.5202 | 11.7687 | 7916 |
| 250.014 | 16.6415 | 8.8650 | 8222 | 230.025 | 19.0742 | 11.7472 | 7917 |
| 260.008 | 17.6717 | 8.8501 | 8223 | 240.020 | 20.6152 | 11.7254 | 7918 |
| 270.002 | 18.6956 | 8.8349 | 8224 | | | | |
| 279.997 | 19.7114 | 8.8197 | 8225 | | | | |
| 289.994 | 20.7215 | 8.8043 | 8226 | 145.996 | 5.5529 | 13.4190 | 7701 |
| | | | | 147.998 | 5.9507 | 13.4141 | 7702 |
| | | | | 150.000 | 6.3460 | 13.4092 | 7703 |
| 143.995 | 5.0676 | 9.7709 | 7601 | 155.005 | 7.3299 | 13.3969 | 7704 |
| 145.996 | 5.3447 | 9.7675 | 7602 | 160.010 | 8.3067 | 13.3846 | 7705 |
| 147.998 | 5.6161 | 9.7641 | 7603 | 165.014 | 9.2833 | 13.3724 | 7706 |
| 150.000 | 5.8835 | 9.7608 | 7604 | 170.019 | 10.2538 | 13.3601 | 7707 |
| 155.005 | 6.5404 | 9.7527 | 7605 | 175.024 | 11.2199 | 13.3478 | 7708 |
| 160.010 | 7.1858 | 9.7446 | 7606 | 180.027 | 12.1821 | 13.3355 | 7709 |
| 165.014 | 7.8231 | 9.7366 | 7607 | 185.030 | 13.1408 | 13.3232 | 7710 |
| 170.019 | 8.4535 | 9.7286 | 7608 | 190.032 | 14.0952 | 13.3108 | 7711 |
| 175.024 | 9.0778 | 9.7206 | 7609 | 195.034 | 15.0452 | 13.2983 | 7712 |
| 180.027 | 9.6972 | 9.7127 | 7610 | 200.035 | 15.9911 | 13.2858 | 7713 |
| 185.030 | 10.3125 | 9.7047 | 7611 | 210.033 | 17.8715 | 13.2606 | 7714 |
| 190.032 | 10.9239 | 9.6968 | 7612 | 220.030 | 19.7353 | 13.2351 | 7715 |
| 195.034 | 11.5312 | 9.6888 | 7613 | 230.025 | 21.5840 | 13.2092 | 7716 |

TABLE 1 . TEMPERATURE-PRESSURE-DENSITY OBSERVATIONS ON FLUORINE--CONTINUED

| TEMP K | PRESSURE MN/M$^2$ | DENSITY MOL/L | IDENT |
|---|---|---|---|
| 145.996 | 5.5803 | 14.4938 | 7301 |
| 147.998 | 6.0136 | 14.4884 | 7302 |
| 150.000 | 6.4479 | 14.4829 | 7303 |
| 155.005 | 7.5346 | 14.4693 | 7304 |
| 160.010 | 8.6223 | 14.4556 | 7305 |
| 165.014 | 9.7090 | 14.4418 | 7306 |
| 170.019 | 10.7932 | 14.4280 | 7307 |
| 175.024 | 11.8746 | 14.4143 | 7308 |
| 180.027 | 12.9527 | 14.4004 | 7309 |
| 185.030 | 14.0275 | 14.3865 | 7310 |
| 190.032 | 15.0986 | 14.3726 | 7311 |
| 195.034 | 16.1651 | 14.3586 | 7312 |
| 200.035 | 17.2279 | 14.3445 | 7313 |
| 210.033 | 19.3406 | 14.3161 | 7314 |
| 220.030 | 21.4361 | 14.2873 | 7315 |
| | | | |
| 145.996 | 5.6063 | 15.7701 | 7102 |
| 147.998 | 6.0859 | 15.7641 | 7103 |
| 150.000 | 6.5689 | 15.7580 | 7104 |
| 155.005 | 7.7889 | 15.7427 | 7105 |
| 160.010 | 9.0163 | 15.7272 | 7106 |
| 165.014 | 10.2477 | 15.7118 | 7107 |
| 170.019 | 11.4795 | 15.6962 | 7108 |
| 175.024 | 12.7098 | 15.6806 | 7109 |
| 180.027 | 13.9387 | 15.6650 | 7110 |
| 185.030 | 15.1641 | 15.6493 | 7111 |
| 190.032 | 16.3858 | 15.6335 | 7112 |
| 195.034 | 17.6042 | 15.6175 | 7113 |
| 200.035 | 18.8182 | 15.6015 | 7114 |
| 210.033 | 21.2328 | 15.5691 | 7115 |
| | | | |
| 145.996 | 5.6826 | 17.9228 | 11801 |
| 147.998 | 6.2544 | 17.9156 | 11802 |
| 150.000 | 6.8366 | 17.9083 | 11803 |
| 155.005 | 8.3181 | 17.8896 | 11804 |
| 160.010 | 9.8205 | 17.8706 | 11805 |
| 165.014 | 11.3329 | 17.8516 | 11806 |
| 170.019 | 12.8497 | 17.8324 | 11807 |
| 175.024 | 14.3668 | 17.8131 | 11808 |
| 180.027 | 15.8834 | 17.7937 | 11809 |
| 185.030 | 17.3973 | 17.7742 | 11810 |
| 190.032 | 18.9083 | 17.7545 | 11811 |
| 195.034 | 20.4147 | 17.7346 | 11812 |
| | | | |
| 145.996 | 5.7462 | 18.7458 | 11501 |
| 147.998 | 6.3635 | 18.7380 | 11502 |
| 150.000 | 6.9921 | 18.7301 | 11503 |
| 155.005 | 8.5924 | 18.7099 | 11504 |
| 160.010 | 10.2157 | 18.6895 | 11505 |
| 165.014 | 11.8507 | 18.6689 | 11506 |
| 170.019 | 13.4911 | 18.6482 | 11507 |
| 175.024 | 15.1326 | 18.6273 | 11508 |
| 180.027 | 16.7728 | 18.6063 | 11509 |
| 185.030 | 18.4107 | 18.5851 | 11510 |
| 190.032 | 20.0447 | 18.5637 | 11511 |
| 195.034 | 21.6738 | 18.5422 | 11512 |
| | | | |
| 150.000 | 7.2527 | 19.7940 | 9101 |
| 155.005 | 9.0246 | 19.7716 | 9102 |
| 160.010 | 10.8216 | 19.7489 | 9103 |
| 165.014 | 12.6306 | 19.7262 | 9104 |
| 170.019 | 14.4455 | 19.7032 | 9105 |
| 175.024 | 16.2603 | 19.6802 | 9106 |
| 180.027 | 18.0749 | 19.6569 | 9107 |
| 185.030 | 19.8847 | 19.6335 | 9108 |
| 190.032 | 21.6917 | 19.6097 | 9109 |
| | | | |
| 143.995 | 5.2963 | 20.6673 | 11401 |
| 145.996 | 6.0273 | 20.6582 | 11402 |
| 147.998 | 6.7749 | 20.6488 | 11403 |
| 150.000 | 7.5327 | 20.6392 | 11404 |
| 155.005 | 9.4574 | 20.6149 | 11405 |
| 160.010 | 11.4063 | 20.5904 | 11406 |
| 165.014 | 13.3667 | 20.5659 | 11407 |
| 170.019 | 15.3332 | 20.5411 | 11408 |
| 175.024 | 17.2983 | 20.5162 | 11409 |
| 180.027 | 19.2617 | 20.4911 | 11410 |
| 185.030 | 21.2213 | 20.4656 | 11411 |
| | | | |
| 143.995 | 5.5541 | 21.8571 | 11701 |
| 145.996 | 6.3880 | 21.8467 | 11702 |
| 147.998 | 7.2345 | 21.8361 | 11703 |
| 150.000 | 8.0903 | 21.8253 | 11704 |
| 155.005 | 10.2564 | 21.7981 | 11705 |
| 160.010 | 12.4430 | 21.7707 | 11706 |
| 165.014 | 14.6396 | 21.7433 | 11707 |
| 170.019 | 16.8381 | 21.7157 | 11708 |
| 175.024 | 19.0347 | 21.6877 | 11709 |
| 180.027 | 21.2276 | 21.6595 | 11710 |
| | | | |
| 143.995 | 5.5550 | 21.8658 | 11301 |
| 145.996 | 6.3896 | 21.8554 | 11302 |
| 147.998 | 7.2372 | 21.8448 | 11303 |
| 150.000 | 8.0928 | 21.8339 | 11304 |
| 155.005 | 10.2602 | 21.8066 | 11305 |
| 160.010 | 12.4475 | 21.7792 | 11306 |
| 165.014 | 14.6451 | 21.7516 | 11307 |
| 170.019 | 16.8455 | 21.7238 | 11308 |
| 175.024 | 19.0414 | 21.6959 | 11309 |
| 180.027 | 21.2361 | 21.6675 | 11310 |
| | | | |
| 141.993 | 5.0864 | 23.0236 | 6801 |
| 143.995 | 6.0185 | 23.0124 | 6802 |
| 145.996 | 6.9648 | 23.0006 | 6803 |
| 147.998 | 7.9207 | 22.9885 | 6804 |
| 150.000 | 8.8832 | 22.9762 | 6805 |
| 155.005 | 11.3096 | 22.9458 | 6806 |
| 160.010 | 13.7511 | 22.9154 | 6807 |
| 165.014 | 16.1970 | 22.8849 | 6808 |
| 170.019 | 18.6432 | 22.8541 | 6809 |
| 175.024 | 21.0844 | 22.8229 | 6810 |
| | | | |
| 139.992 | 4.6408 | 24.1656 | 11201 |
| 141.993 | 5.6875 | 24.1528 | 11202 |
| 143.995 | 6.7473 | 24.1395 | 11203 |
| 145.996 | 7.8162 | 24.1259 | 11204 |
| 147.998 | 8.8917 | 24.1123 | 11205 |
| 150.000 | 9.9710 | 24.0989 | 11206 |
| 155.005 | 12.6845 | 24.0653 | 11207 |
| 160.010 | 15.4054 | 24.0316 | 11208 |
| 165.014 | 18.1249 | 23.9977 | 11209 |
| 170.019 | 20.8398 | 23.9633 | 11210 |
| | | | |
| 137.990 | 4.3981 | 25.4197 | 11101 |
| 139.992 | 5.5916 | 25.4051 | 11102 |
| 141.993 | 6.7956 | 25.3899 | 11103 |

TABLE 1 . TEMPERATURE-PRESSURE-DENSITY OBSERVATIONS ON FLUORINE--CONTINUED

| TEMP K | PRESSURE MN/M$^2$ | DENSITY MOL/L | IDENT |
|---|---|---|---|
| 143.995 | 8.0063 | 25.3744 | 11104 |
| 145.996 | 9.2228 | 25.3591 | 11105 |
| 147.998 | 10.4416 | 25.3440 | 11106 |
| 150.000 | 11.6629 | 25.3290 | 11107 |
| 155.005 | 14.7193 | 25.2915 | 11108 |
| 160.010 | 17.7735 | 25.2537 | 11109 |
| 165.014 | 20.8210 | 25.2154 | 11110 |
| | | | |
| 135.989 | 4.2576 | 26.5253 | 6701 |
| 137.990 | 5.5957 | 26.5094 | 6702 |
| 139.992 | 6.9422 | 26.4921 | 6703 |
| 141.993 | 8.2923 | 26.4750 | 6704 |
| 143.995 | 9.6452 | 26.4584 | 6705 |
| 145.996 | 11.0021 | 26.4420 | 6706 |
| 147.998 | 12.3580 | 26.4255 | 6707 |
| 150.000 | 13.7136 | 26.4091 | 6708 |
| 155.005 | 17.1002 | 26.3679 | 6709 |
| 160.010 | 20.4746 | 26.3261 | 6710 |
| | | | |
| 135.989 | 6.1799 | 27.7894 | 8601 |
| 139.992 | 9.2435 | 27.7508 | 8602 |
| 145.996 | 13.8358 | 27.6951 | 8603 |
| 150.000 | 16.8861 | 27.6579 | 8604 |
| | | | |
| 131.987 | 3.1337 | 27.8278 | 3001 |
| 133.988 | 4.6569 | 27.8076 | 3002 |
| 135.989 | 6.1838 | 27.7893 | 3003 |
| 137.990 | 7.7142 | 27.7695 | 3004 |
| 139.992 | 9.2456 | 27.7509 | 3005 |
| 141.993 | 10.7772 | 27.7324 | 3006 |
| 143.995 | 12.3076 | 27.7139 | 3007 |
| 145.996 | 13.8350 | 27.6954 | 3008 |
| 147.998 | 15.3607 | 27.6769 | 3009 |
| 150.000 | 16.8833 | 27.6584 | 3010 |
| 155.005 | 20.6776 | 27.6116 | 3011 |
| | | | |
| 129.987 | 3.1750 | 28.7586 | 6601 |
| 131.987 | 4.8498 | 28.7366 | 6602 |
| 133.988 | 6.5264 | 28.7154 | 6603 |
| 135.989 | 8.2033 | 28.6953 | 6604 |
| 137.990 | 9.8768 | 28.6752 | 6605 |
| 139.992 | 11.5492 | 28.6552 | 6606 |
| 141.993 | 13.2188 | 28.6352 | 6607 |
| 143.995 | 14.8842 | 28.6153 | 6608 |
| 145.996 | 16.5472 | 28.5953 | 6609 |
| 147.998 | 18.2059 | 28.5752 | 6610 |
| 150.000 | 19.8604 | 28.5551 | 6611 |
| 152.002 | 21.5104 | 28.5348 | 6612 |
| | | | |
| 129.987 | 5.1513 | 29.5967 | 8701 |
| 133.988 | 8.7944 | 29.5529 | 8702 |
| 139.992 | 14.2282 | 29.4876 | 8703 |
| 147.998 | 21.4010 | 29.4005 | 8704 |
| | | | |
| 123.987 | 2.0663 | 30.5991 | 3301 |
| 125.987 | 4.0717 | 30.5717 | 3302 |
| 127.987 | 6.0736 | 30.5458 | 3303 |
| 129.987 | 8.0687 | 30.5223 | 3304 |
| 131.987 | 10.0571 | 30.4985 | 3305 |
| 133.988 | 12.0370 | 30.4748 | 3306 |
| 135.989 | 14.0095 | 30.4512 | 3307 |
| 137.990 | 15.9751 | 30.4277 | 3308 |
| 139.992 | 17.9331 | 30.4041 | 3309 |
| 141.993 | 19.8854 | 30.3804 | 3310 |
| 143.995 | 21.8300 | 30.3565 | 3311 |
| | | | |
| 123.987 | 2.5342 | 30.7537 | 11001 |
| 125.987 | 4.5717 | 30.7266 | 11002 |
| 127.987 | 6.6241 | 30.7009 | 11003 |
| 129.987 | 8.6274 | 30.6770 | 11004 |
| 131.987 | 10.6449 | 30.6528 | 11005 |
| 133.988 | 12.6542 | 30.6288 | 11006 |
| 135.989 | 14.6559 | 30.6048 | 11007 |
| 137.990 | 16.6506 | 30.5808 | 11008 |
| 139.992 | 18.6381 | 30.5568 | 11009 |
| 141.993 | 20.6167 | 30.5326 | 11010 |
| | | | |
| 121.988 | 2.1204 | 31.2838 | 6501 |
| 123.987 | 4.2621 | 31.2549 | 6502 |
| 125.987 | 6.3997 | 31.2282 | 6503 |
| 127.987 | 8.5275 | 31.2031 | 6504 |
| 129.987 | 10.6450 | 31.1779 | 6505 |
| 131.987 | 12.7562 | 31.1528 | 6506 |
| 133.988 | 14.8557 | 31.1280 | 6507 |
| 135.989 | 16.9441 | 31.1032 | 6508 |
| 137.990 | 19.0306 | 31.0783 | 6509 |
| 139.992 | 21.1040 | 31.0533 | 6510 |
| | | | |
| 119.989 | 2.0538 | 31.8837 | 10901 |
| 121.988 | 4.3243 | 31.8531 | 10902 |
| 123.987 | 6.5827 | 31.8252 | 10903 |
| 125.987 | 8.8306 | 31.7984 | 10904 |
| 127.987 | 11.0664 | 31.7717 | 10905 |
| 129.987 | 13.2909 | 31.7452 | 10906 |
| 131.987 | 15.5074 | 31.7189 | 10907 |
| 133.988 | 17.7116 | 31.6926 | 10908 |
| 135.989 | 19.9058 | 31.6661 | 10909 |
| 137.990 | 22.0927 | 31.6394 | 10910 |
| | | | |
| 119.989 | 2.0907 | 31.8967 | 9901 |
| 121.988 | 4.3610 | 31.8659 | 9902 |
| 123.987 | 6.6209 | 31.8379 | 9903 |
| 125.987 | 8.8700 | 31.8109 | 9904 |
| 127.987 | 11.1072 | 31.7840 | 9905 |
| 129.987 | 13.3333 | 31.7573 | 9906 |
| 131.987 | 15.5502 | 31.7308 | 9907 |
| 133.988 | 17.7548 | 31.7043 | 9908 |
| 135.989 | 19.9523 | 31.6777 | 9909 |
| 137.990 | 22.1410 | 31.6508 | 9910 |
| | | | |
| 117.991 | 1.8073 | 32.4138 | 5601 |
| 119.989 | 4.1910 | 32.3815 | 5602 |
| 121.988 | 6.5648 | 32.3525 | 5603 |
| 123.987 | 8.9247 | 32.3246 | 5604 |
| 125.987 | 11.2704 | 32.2967 | 5605 |
| 127.987 | 13.6024 | 32.2691 | 5606 |
| 129.987 | 15.9198 | 32.2416 | 5607 |
| 131.987 | 18.2273 | 32.2141 | 5608 |
| 133.988 | 20.5256 | 32.1863 | 5609 |
| | | | |
| 117.991 | 3.8594 | 32.8504 | 8801 |
| 121.988 | 8.8046 | 32.7903 | 8802 |

TABLE 1 . TEMPERATURE-PRESSURE-DENSITY OBSERVATIONS ON FLUORINE--CONTINUED

| TEMP K | PRESSURE MN/M$^2$ | DENSITY MOL/L | IDENT |
|---|---|---|---|
| 125.987 | 13.6829 | 32.7320 | 8803 |
| 131.987 | 20.9035 | 32.6457 | 8804 |
| | | | |
| 115.993 | 1.3862 | 32.8854 | 3501 |
| 117.991 | 3.8764 | 32.8507 | 3502 |
| 119.989 | 6.3523 | 32.8203 | 3503 |
| 121.988 | 8.8139 | 32.7911 | 3504 |
| 123.987 | 11.2577 | 32.7619 | 3505 |
| 125.987 | 13.6896 | 32.7332 | 3506 |
| 127.987 | 16.1053 | 32.7047 | 3507 |
| 129.987 | 18.5101 | 32.6761 | 3508 |
| 131.987 | 20.9029 | 32.6473 | 3509 |
| | | | |
| 113.995 | 1.4096 | 33.4281 | 2801 |
| 115.993 | 4.0243 | 33.3920 | 2802 |
| 117.991 | 6.6219 | 33.3603 | 2803 |
| 119.989 | 9.2038 | 33.3296 | 2804 |
| 121.988 | 11.7677 | 33.2990 | 2805 |
| 123.987 | 14.3135 | 33.2691 | 2806 |
| 125.987 | 16.8497 | 33.2396 | 2807 |
| 127.987 | 19.3713 | 33.2097 | 2808 |
| 129.987 | 21.8803 | 33.1795 | 2809 |
| | | | |
| 113.995 | 1.3999 | 33.4306 | 9301 |
| 115.993 | 4.0187 | 33.3942 | 9302 |
| 117.991 | 6.6221 | 33.3625 | 9303 |
| 119.989 | 9.2074 | 33.3315 | 9304 |
| 121.988 | 11.7742 | 33.3008 | 9305 |
| 123.987 | 14.3248 | 33.2707 | 9306 |
| 125.987 | 16.8605 | 33.2407 | 9307 |
| 127.987 | 19.3844 | 33.2106 | 9308 |
| 129.987 | 21.8939 | 33.1800 | 9309 |
| | | | |
| 111.996 | 1.2522 | 33.9215 | 6401 |
| 113.995 | 3.9918 | 33.8833 | 6402 |
| 115.993 | 6.7161 | 33.8504 | 6403 |
| 117.991 | 9.4152 | 33.8181 | 6404 |
| 119.989 | 12.0947 | 33.7862 | 6405 |
| 121.988 | 14.7578 | 33.7550 | 6406 |
| 123.987 | 17.4042 | 33.7239 | 6407 |
| 125.987 | 20.0399 | 33.6925 | 6408 |
| 127.987 | 22.6598 | 33.6609 | 6409 |
| | | | |
| 111.996 | 3.7877 | 34.3287 | 9401 |
| 113.995 | 6.6219 | 34.2945 | 9402 |
| 115.993 | 9.4336 | 34.2606 | 9403 |
| 117.991 | 12.2178 | 34.2276 | 9404 |
| 119.989 | 14.9846 | 34.1951 | 9405 |
| 121.988 | 17.7393 | 34.1625 | 9406 |
| 123.987 | 20.4747 | 34.1298 | 9407 |
| | | | |
| 109.998 | 0.9643 | 34.3721 | 3201 |
| 111.996 | 3.8173 | 34.3315 | 3202 |
| 113.995 | 6.6497 | 34.2974 | 3203 |
| 115.993 | 9.4560 | 34.2637 | 3204 |
| 117.991 | 12.2408 | 34.2307 | 3205 |
| 119.989 | 15.0052 | 34.1983 | 3206 |
| 121.988 | 17.7529 | 34.1658 | 3207 |
| 123.987 | 20.4844 | 34.1332 | 3208 |
| | | | |
| 108.000 | 1.8893 | 34.9904 | 9701 |
| 109.998 | 4.9055 | 34.9504 | 9702 |
| 111.996 | 7.8958 | 34.9153 | 9703 |
| 113.995 | 10.8562 | 34.8796 | 9704 |
| 115.993 | 13.7914 | 34.8451 | 9705 |
| 117.991 | 16.7036 | 34.8109 | 9706 |
| 119.989 | 19.5986 | 34.7764 | 9707 |
| 121.988 | 22.4815 | 34.7415 | 9708 |
| | | | |
| 106.002 | 1.3049 | 35.3710 | 5301 |
| 108.000 | 4.4265 | 35.3281 | 5302 |
| 109.998 | 7.5173 | 35.2916 | 5303 |
| 111.996 | 10.5819 | 35.2546 | 5304 |
| 113.995 | 13.6157 | 35.2192 | 5305 |
| 115.993 | 16.6268 | 35.1841 | 5306 |
| 117.991 | 19.6241 | 35.1489 | 5307 |
| 119.989 | 22.6020 | 35.1132 | 5308 |
| | | | |
| 108.000 | 4.4294 | 35.3292 | 8901 |
| 111.996 | 10.5904 | 35.2558 | 8902 |
| 115.993 | 16.6385 | 35.1848 | 8903 |
| 119.989 | 22.6077 | 35.1134 | 8904 |
| | | | |
| 104.005 | 1.7569 | 35.8759 | 9801 |
| 106.002 | 5.0226 | 35.8326 | 9802 |
| 108.000 | 8.2535 | 35.7945 | 9803 |
| 109.998 | 11.4495 | 35.7565 | 9804 |
| 111.996 | 14.6184 | 35.7196 | 9805 |
| 113.995 | 17.7614 | 35.6826 | 9806 |
| 115.993 | 20.8837 | 35.6453 | 9807 |
| | | | |
| 102.008 | 0.9747 | 36.2163 | 5501 |
| 104.005 | 4.3398 | 36.1697 | 5502 |
| 106.002 | 7.6717 | 36.1303 | 5503 |
| 108.000 | 10.9641 | 36.0910 | 5504 |
| 109.998 | 14.2237 | 36.0531 | 5505 |
| 111.996 | 17.4597 | 36.0153 | 5506 |
| 113.995 | 20.6766 | 35.9771 | 5507 |
| | | | |
| 102.008 | 1.2377 | 36.2449 | 5701 |
| 104.005 | 4.6118 | 36.1990 | 5702 |
| 106.002 | 7.9501 | 36.1594 | 5703 |
| 108.000 | 11.2504 | 36.1203 | 5704 |
| 109.998 | 14.5134 | 36.0819 | 5705 |
| 111.996 | 17.7568 | 36.0440 | 5706 |
| 113.995 | 20.9811 | 36.0056 | 5707 |
| | | | |
| 102.008 | 3.9537 | 36.5444 | 9501 |
| 104.005 | 7.4001 | 36.5033 | 9502 |
| 106.002 | 10.7999 | 36.4627 | 9503 |
| 108.000 | 14.1678 | 36.4237 | 9504 |
| 109.998 | 17.5067 | 36.3846 | 9505 |
| 111.996 | 20.8277 | 36.3452 | 9506 |
| | | | |
| 100.010 | 0.4947 | 36.5951 | 2901 |
| 102.008 | 3.9704 | 36.5447 | 2902 |
| 104.005 | 7.4128 | 36.5043 | 2903 |
| 106.002 | 10.8108 | 36.4638 | 2904 |
| 108.000 | 14.1772 | 36.4249 | 2905 |
| 109.998 | 17.5172 | 36.3861 | 2906 |
| 111.996 | 20.8393 | 36.3469 | 2907 |

TABLE 1 . TEMPERATURE-PRESSURE-DENSITY OBSERVATIONS ON FLUORINE--CONTINUED

| TEMP K | PRESSURE MN/M$^2$ | DENSITY MOL/L | IDENT |
|---|---|---|---|
| 98.012 | 0.8850 | 37.0590 | 5101 |
| 100.010 | 4.5114 | 37.0089 | 5102 |
| 102.008 | 8.0937 | 36.9662 | 5103 |
| 104.005 | 11.6289 | 36.9252 | 5104 |
| 106.002 | 15.1285 | 36.8847 | 5105 |
| 108.000 | 18.6042 | 36.8442 | 5106 |
| 109.998 | 22.0614 | 36.8031 | 5107 |
| | | | |
| 98.012 | 4.9668 | 37.4461 | 9201 |
| 102.008 | 12.3521 | 37.3597 | 9202 |
| 104.005 | 15.9787 | 37.3177 | 9203 |
| 106.002 | 19.5824 | 37.2755 | 9204 |
| 108.000 | 23.1667 | 37.2326 | 9205 |
| | | | |
| 94.013 | 1.3101 | 37.9022 | 10001 |
| 96.013 | 5.2104 | 37.8533 | 10002 |
| 98.012 | 9.0596 | 37.8054 | 10003 |
| 100.010 | 12.8559 | 37.7618 | 10004 |
| 102.008 | 16.6183 | 37.7182 | 10005 |
| 104.005 | 20.3521 | 37.6744 | 10006 |
| | | | |
| 94.013 | 1.3182 | 37.9060 | 5001 |
| 96.013 | 5.2200 | 37.8572 | 5002 |
| 98.012 | 9.0684 | 37.8094 | 5003 |
| 100.010 | 12.8621 | 37.7659 | 5004 |
| 102.008 | 16.6237 | 37.7225 | 5005 |
| 104.005 | 20.3536 | 37.6789 | 5006 |
| | | | |
| 92.012 | 1.6868 | 38.3248 | 9601 |
| 94.013 | 5.7328 | 38.2752 | 9602 |
| 96.013 | 9.7164 | 38.2263 | 9603 |
| 98.012 | 13.6445 | 38.1812 | 9604 |
| 100.010 | 17.5364 | 38.1360 | 9605 |
| 102.008 | 21.4026 | 38.0904 | 9606 |
| | | | |
| 90.010 | 0.9805 | 38.6564 | 5201 |
| 92.012 | 5.1494 | 38.6036 | 5202 |
| 94.013 | 9.2524 | 38.5525 | 5203 |
| 96.013 | 13.2953 | 38.5062 | 5204 |
| 98.012 | 17.3028 | 38.4601 | 5205 |
| 100.010 | 21.2828 | 38.4135 | 5206 |
| | | | |
| 90.010 | 4.7415 | 38.9389 | 9001 |
| 94.013 | 13.1362 | 38.8416 | 9002 |
| 98.012 | 21.3414 | 38.7459 | 9003 |
| | | | |
| 88.005 | 0.4645 | 39.0005 | 4601 |
| 90.010 | 4.7619 | 38.9402 | 4602 |
| 92.012 | 8.9965 | 38.8907 | 4603 |
| 94.013 | 13.1625 | 38.8431 | 4604 |
| 96.013 | 17.2837 | 38.7957 | 4605 |
| 98.012 | 21.3782 | 38.7476 | 4606 |
| | | | |
| 86.000 | 0.3367 | 39.3667 | 3401 |
| 88.005 | 4.7559 | 39.3037 | 3402 |
| 90.010 | 9.1085 | 39.2529 | 3403 |
| 92.012 | 13.3967 | 39.2040 | 3404 |
| 94.013 | 17.6480 | 39.1552 | 3405 |
| 96.013 | 21.8622 | 39.1059 | 3406 |
| 88.005 | 4.7505 | 39.3046 | 10101 |
| 90.010 | 9.1162 | 39.2535 | 10102 |
| 92.012 | 13.4113 | 39.2043 | 10103 |
| 94.013 | 17.6633 | 39.1551 | 10104 |
| 96.013 | 21.8822 | 39.1052 | 10105 |
| | | | |
| 83.995 | 0.4459 | 39.7405 | 10501 |
| 86.000 | 5.0134 | 39.6764 | 10502 |
| 88.005 | 9.5029 | 39.6242 | 10503 |
| 90.010 | 13.9204 | 39.5735 | 10504 |
| 92.012 | 18.3051 | 39.5229 | 10505 |
| 94.013 | 22.6595 | 39.4713 | 10506 |
| | | | |
| 83.995 | 0.4651 | 39.7423 | 4501 |
| 86.000 | 5.0379 | 39.6788 | 4502 |
| 88.005 | 9.5411 | 39.6268 | 4503 |
| 90.010 | 13.9741 | 39.5764 | 4504 |
| 92.012 | 18.3629 | 39.5259 | 4505 |
| 94.013 | 22.7325 | 39.4744 | 4506 |
| | | | |
| 81.992 | 0.4370 | 40.1067 | 10801 |
| 83.995 | 5.1394 | 40.0403 | 10802 |
| 86.000 | 9.7620 | 39.9880 | 10803 |
| 88.005 | 14.3199 | 39.9359 | 10804 |
| 90.010 | 18.8417 | 39.8836 | 10805 |
| 92.012 | 23.3386 | 39.8303 | 10806 |
| | | | |
| 81.992 | 0.4377 | 40.1072 | 4201 |
| 83.995 | 5.1391 | 40.0409 | 4202 |
| 86.000 | 9.7704 | 39.9887 | 4203 |
| 88.005 | 14.3384 | 39.9367 | 4204 |
| 90.010 | 18.8670 | 39.8846 | 4205 |
| 92.012 | 23.3699 | 39.8314 | 4206 |
| | | | |
| 79.991 | 0.4890 | 40.4642 | 10201 |
| 81.992 | 5.3375 | 40.3965 | 10202 |
| 83.995 | 10.0991 | 40.3430 | 10203 |
| 86.000 | 14.7862 | 40.2894 | 10204 |
| 88.005 | 19.4396 | 40.2353 | 10205 |
| | | | |
| 79.991 | 0.4945 | 40.4640 | 4401 |
| 81.992 | 5.3375 | 40.3965 | 4402 |
| 83.995 | 10.0956 | 40.3432 | 4403 |
| 86.000 | 14.7864 | 40.2897 | 4404 |
| 88.005 | 19.4439 | 40.2359 | 4405 |
| | | | |
| 77.991 | 1.4832 | 40.8761 | 10301 |
| 79.991 | 6.4748 | 40.8127 | 10302 |
| 81.992 | 11.3732 | 40.7571 | 10303 |
| 83.995 | 16.2170 | 40.7016 | 10304 |
| 86.000 | 21.0321 | 40.6455 | 10305 |
| | | | |
| 75.993 | 1.6279 | 41.2328 | 6301 |
| 77.991 | 6.7642 | 41.1688 | 6302 |
| 79.991 | 11.7882 | 41.1121 | 6303 |
| 81.992 | 16.7735 | 41.0553 | 6304 |
| 83.995 | 21.7365 | 40.9977 | 6305 |

TABLE 1. TEMPERATURE-PRESSURE-DENSITY OBSERVATIONS ON FLUORINE--CONTINUED

| TEMP K | PRESSURE MN/M$^2$ | DENSITY MOL/L | IDENT |
|---|---|---|---|
| 73.996 | 0.4564 | 41.5151 | 4301 |
| 75.993 | 5.7320 | 41.4434 | 4302 |
| 77.991 | 10.8956 | 41.3656 | 4303 |
| 79.991 | 15.9845 | 41.3278 | 4304 |
| 81.992 | 21.0491 | 41.2691 | 4305 |
| | | | |
| 73.996 | 0.4815 | 41.5190 | 10601 |
| 75.993 | 5.7438 | 41.4471 | 10602 |
| 77.991 | 10.8992 | 41.3889 | 10603 |
| 79.991 | 15.9884 | 41.3308 | 10604 |
| 81.992 | 21.0641 | 41.2719 | 10605 |
| | | | |
| 73.996 | 0.5595 | 41.5209 | 10401 |
| 75.993 | 5.8320 | 41.4497 | 10402 |
| 77.991 | 10.9885 | 41.3914 | 10403 |
| 79.991 | 16.0681 | 41.3333 | 10404 |
| 81.992 | 21.1332 | 41.2744 | 10405 |
| | | | |
| 71.998 | 0.8278 | 41.8772 | 6101 |
| 73.996 | 6.2426 | 41.8068 | 6102 |
| 75.993 | 11.5453 | 41.7467 | 6103 |
| 77.991 | 16.7781 | 41.6867 | 6104 |
| 79.991 | 21.9801 | 41.6259 | 6105 |
| | | | |
| 70.000 | 0.4372 | 42.1990 | 10701 |
| 71.998 | 6.0066 | 42.1238 | 10702 |
| 73.996 | 11.4350 | 42.0624 | 10703 |
| 75.993 | 16.8041 | 42.0012 | 10704 |
| 77.991 | 22.1545 | 41.9388 | 10705 |
| | | | |
| 70.000 | 0.4585 | 42.1996 | 4101 |
| 71.998 | 6.0266 | 42.1252 | 4102 |
| 73.996 | 11.4696 | 42.0640 | 4103 |
| 75.993 | 16.8566 | 42.0028 | 4104 |
| 77.991 | 22.2168 | 41.9406 | 4105 |
| | | | |
| 68.001 | 0.8566 | 42.5531 | 6001 |
| 70.000 | 6.5671 | 42.4798 | 6002 |
| 71.998 | 12.1452 | 42.4164 | 6003 |
| 73.996 | 17.6633 | 42.3532 | 6004 |
| 75.993 | 23.1733 | 42.2884 | 6005 |
| | | | |
| 66.000 | 0.8508 | 42.8768 | 5901 |
| 68.001 | 6.7269 | 42.8021 | 5902 |
| 70.000 | 12.4546 | 42.7372 | 5903 |
| 71.998 | 18.1377 | 42.6724 | 5904 |
| 73.996 | 23.7925 | 42.6058 | 5905 |
| | | | |
| 63.999 | 0.9133 | 43.2041 | 5401 |
| 66.000 | 6.9342 | 43.1279 | 5402 |
| 68.001 | 12.8113 | 43.0610 | 5403 |
| 70.000 | 18.6316 | 42.9941 | 5404 |
| | | | |
| 63.999 | 1.2662 | 43.2189 | 4901 |
| 66.000 | 7.2989 | 43.1446 | 4902 |
| 68.001 | 13.1924 | 43.0780 | 4903 |
| 70.000 | 19.0462 | 43.0114 | 4904 |

| TEMP K | PRESSURE MN/M$^2$ | DENSITY MOL/L | IDENT |
|---|---|---|---|
| 61.998 | 1.2361 | 43.5478 | 5801 |
| 63.999 | 7.4169 | 43.4718 | 5802 |
| 66.000 | 13.4638 | 43.4033 | 5803 |
| 68.001 | 19.4467 | 43.3348 | 5804 |
| | | | |
| 59.999 | 0.5011 | 43.8506 | 4701 |
| 61.998 | 6.8268 | 43.7690 | 4702 |
| 63.999 | 13.0040 | 43.6990 | 4703 |
| 66.000 | 19.1342 | 43.6290 | 4704 |
| | | | |
| 59.999 | 0.5139 | 43.8515 | 11601 |
| 61.998 | 6.8361 | 43.7701 | 11602 |
| 63.999 | 13.0332 | 43.7001 | 11603 |
| 66.000 | 19.1699 | 43.6300 | 11604 |
| | | | |
| 58.002 | 1.5812 | 44.2038 | 4801 |
| 59.999 | 8.0600 | 44.1262 | 4802 |
| 61.998 | 14.4207 | 44.0544 | 4803 |
| 63.999 | 20.7475 | 43.9822 | 4804 |
| | | | |
| 56.005 | 1.4389 | 44.5234 | 6201 |
| 58.002 | 8.0623 | 44.4435 | 6202 |
| 59.999 | 14.5535 | 44.3698 | 6203 |
| 61.998 | 21.0109 | 44.2954 | 6204 |
| | | | |
| 56.005 | 4.8597 | 44.6360 | 12201 |
| 58.002 | 11.4722 | 44.5618 | 12202 |
| 59.999 | 18.0087 | 44.4877 | 12203 |
| 61.998 | 24.5494 | 44.4105 | 12204 |
| | | | |
| 53.610 | 1.3141 | | 12001 |
| 53.709 | 2.3350 | | 12002 |
| 53.809 | 3.3653 | | 12003 |
| 53.909 | 4.3943 | | 12004 |
| 54.009 | 5.0652 | 44.9752 | 12005 |
| 54.109 | 5.4099 | 44.9721 | 12006 |
| 54.209 | 5.7571 | 44.9682 | 12007 |
| 55.007 | 8.5036 | 44.9373 | 12008 |
| 56.005 | 11.8881 | 44.8989 | 12009 |
| 58.002 | 18.5846 | 44.8229 | 12010 |
| | | | |
| 53.909 | 4.3901 | | 12101 |
| 54.009 | 5.4182 | | 12102 |
| 54.109 | 6.4487 | | 12103 |
| 54.209 | 7.4857 | | 12104 |
| 54.309 | 8.5322 | | 12105 |
| 54.408 | 9.5650 | | 12106 |
| 54.508 | 10.6060 | | 12107 |
| 54.608 | 11.6500 | | 12108 |
| 54.708 | 12.6979 | | 12109 |
| 54.808 | 13.7392 | | 12110 |
| 54.907 | 14.7088 | 45.1393 | 12111 |
| 55.007 | 15.0681 | 45.1353 | 12112 |
| 55.107 | 15.4160 | 45.1315 | 12113 |
| 56.005 | 18.4968 | 45.0966 | 12114 |

The estimated accuracy of the density measurements is 0.1 percent. However, the corresponding precision is better, indicated by the fact that the standard deviation of all *PVT* data from eqs (1) and (5) is approximately 0.02 percent in density.

The purity of the fluorine sample used for these measurements was 99.99 percent as determined from residual gas analysis after reaction of fluorine with mercury.

## 3. Representation of *PVT* Data

No single equation of state was found capable of representing the data to within its precision. Therefore, to obtain the best possible representation of all the data for computation of thermodynamic functions, the *PVT* surface was divided into two regions as pictured in figure 1. The data in each region were correlated separately as discussed below.

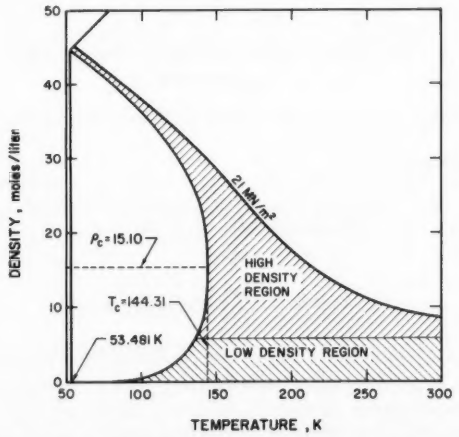


FIGURE 1. *Density-temperature diagram showing the regions used for representation of the* PVT *data.*

### 3.1. Low-Density Region

All experimental *PVT* data at densities less than 6.0 mol/l were represented by the truncated virial equation

$$P = RT[\rho + B(T)\rho^2 + C(T)\rho^3] \tag{1}$$

where $R = 8.3143$ J/mol−K. The decision to use 6.0 mol/l as a maximum density value for the virial surface was based on the results obtained by fitting the experimental data to eq (1). By varying the maximum experimental density included in the fit of the virial equation, the data were found to exhibit definite systematic deviations in density as well as temperature for all densities greater than 6.0 mol/l. Equation (1) was based on 329 *PVT* data points in the virial region. Further, 26 measured specific heat ($C_v$) data points [9] between 6.5 and 6.8 mol/l at temperatures from 140 K to 300 K were compared to $C_v$ values calculated from the virial equation and the ideal gas values, $C_v^\circ$ [8]. The reason for this was to ascertain that the apparent deviations, being of the order of 1.5 percent, were fairly constant and not a function of temperature.

The second and third virial coefficients were represented by

$$B(T) = \sum_{i=1}^{5} B_i T^{(1-i)/4} \tag{1a}$$

and

$$C(T) = \sum_{i=1}^{6} C_i T^{(1-i)/2}, \tag{1b}$$

respectively. An iterative method was used to optimize both the number of coefficients of $B(T)$ and $C(T)$ and their temperature dependence. The coefficients of eqs (1a) and (1b) and their significance level obtained through a weighted least-squares fit of all *PVT* data in this region are given in table 2. Weight factors, $W$, used in the fitting of eq (1) were defined as

TABLE 2. *Least squares estimate of the coefficients of eqs (1a) and (1b)*

| Coefficient | Least squares estimate of coefficient | Standard deviation of coefficient | Significance level in percent [a] |
|---|---|---|---|
| $B_1$ | $-4.43719523$ | 1.10 | 99.9+ |
| $B_2$ | $6.88646977 \times 10$ | $1.61 \times 10$ | 99.9+ |
| $B_3$ | $-4.00652537 \times 10^2$ | $8.85 \times 10$ | 99.9+ |
| $B_4$ | $1.04730534 \times 10^3$ | $2.15 \times 10^2$ | 99.9+ |
| $B_5$ | $-1.05492603 \times 10^3$ | $1.96 \times 10^2$ | 99.9+ |
| $C_1$ | $3.97288149 \times 10^{-1}$ | $6.38 \times 10^{-2}$ | 99.9+ |
| $C_2$ | $-2.80769183 \times 10$ | 4.33 | 99.9+ |
| $C_3$ | $7.95698766 \times 10^2$ | $1.18 \times 10^2$ | 99.9+ |
| $C_4$ | $-1.12867697 \times 10^4$ | $1.59 \times 10^3$ | 99.9+ |
| $C_5$ | $8.01450388 \times 10^4$ | $1.08 \times 10^4$ | 99.9+ |
| $C_6$ | $-2.27594177 \times 10^5$ | $2.93 \times 10^4$ | 99.9+ |

[a] These parameters are significant at the level indicated when applying the standard $F$-test.

$$W = \frac{1}{\sigma_p^2 + \left(\frac{\partial P}{\partial \rho}\sigma_\rho\right)^2 + \left(\frac{\partial P}{\partial T}\sigma_T\right)^2} \tag{2}$$

where $\sigma_p^2$, $\sigma_\rho^2$, $\sigma_T^2$ are the respective variances in pressure, density, and temperature. *PVT* data below 100 K were weighted relatively less than above this temperature, as the uncertainty of the measurements in this region increases rapidly with decreasing density. The weighted standard deviation in density between the virial surface and all of the 329 *PVT* data points is 0.041 percent. For consistency eq (1) was constrained to give the proper saturation temperature (137.327 K) for the 6.0 mol/l isochore [2].

The second and third virial coefficients, calculated from eqs (1a) and (1b), are given in table 3. Also given in this table are the quantities $\delta B$ and $\delta C$, which are the respective estimated uncertainties of the coefficients based on experience gained when fitting the virial surface. A comparison of the second virial coefficient with values obtained by White, Hu, and

TABLE 3. *Second and third virial coefficients of fluorine*

($\delta B$ and $\delta C$ are estimated uncertainties)

| $T$ | $B$ | $\delta B \times 10^3$ | C | $\delta C \times 10^3$ |
|---|---|---|---|---|
| K | l/mol | l/mol | $l/mol^2$ | $(l/mol)^2$ |
| 80 | −0.2396 | 40 | −0.022557 | 20 |
| 85 | −.2132 | | −.013548 | |
| 90 | −.1910 | | −.007748 | |
| 95 | −.1722 | | −.004016 | |
| 100 | −.1561 | 10 | −.001624 | 3 |
| 105 | −.1422 | | −.000106 | |
| 110 | −.1301 | | .000838 | |
| 115 | −.1194 | | .001409 | |
| 120 | −.1100 | | .001736 | |
| 125 | −.1017 | 2 | .001905 | 0.5 |
| 130 | −.0942 | | .001973 | |
| 135 | −.0875 | | .001979 | |
| 140 | −.0815 | | .001947 | |
| 145 | −.0759 | | .001893 | |
| 150 | −.0709 | 0.3 | .001828 | .03 |
| 155 | −.0663 | | .001758 | |
| 160 | −.0621 | | .001689 | |
| 165 | −.0582 | | .001621 | |
| 170 | −.0546 | | .001557 | |
| 175 | −.0512 | | .001498 | |
| 180 | −.0481 | | .001442 | |
| 185 | −.0452 | | .001391 | |
| 190 | −.0425 | | .001344 | |
| 195 | −.0400 | | .001301 | |
| 200 | −.0376 | .3 | .001261 | .03 |
| 205 | −.0354 | | .001224 | |
| 210 | −.0332 | | .001190 | |
| 215 | −.0313 | | .001159 | |
| 220 | −.0294 | | .001130 | |
| 225 | −.0276 | | .001104 | |
| 230 | −.0259 | | .001080 | |
| 235 | −.0243 | | .001057 | |
| 240 | −.0228 | | .001037 | |
| 245 | −.0214 | | .001019 | |
| 250 | −.0200 | .3 | .001003 | .03 |
| 255 | −.0187 | | .000988 | |
| 260 | −.0175 | | .000976 | |
| 265 | −.0163 | | .000966 | |
| 270 | −.0152 | | .000957 | |
| 275 | −.0141 | | .000951 | |
| 280 | −.0131 | | .000947 | |
| 285 | −.0122 | | .000946 | |
| 290 | −.0112 | | .000946 | |
| 295 | −.0104 | | .000949 | |
| 300 | −.0095 | .3 | .000955 | .04 |

Johnston [10] is given in figure 2. In the calculation of their data these authors neglected the contribution of the third and higher order virial coefficients, which is the probable reason for their larger negative values, especially at lower temperatures. Temperature scale differences could also account for part of the deviations. Since the data from reference [10] do not represent just the second virial coefficient, further comparisons with eq (1a) were made by converting values from oxygen [11] and argon [12] using corresponding states approach based on critical parameters

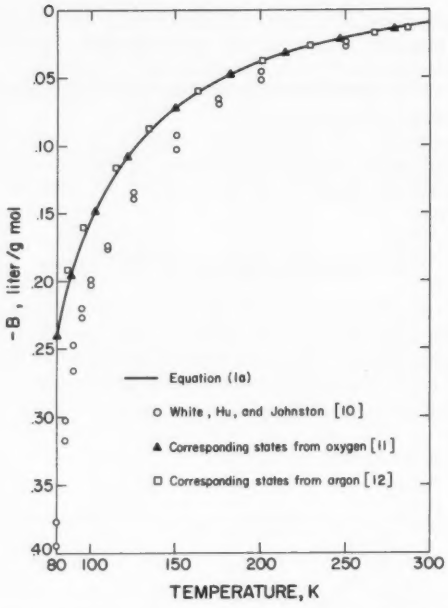


FIGURE 2. *Comparisons of second virial coefficients of fluorine.*

as follows:

$$B_{\text{converted}} = B(X)\,\frac{\rho_c(X)}{\rho_c(F_2)} \tag{3}$$

and

$$T_{\text{converted}} = T(X)\,\frac{T_c(F_2)}{T_c(X)} \tag{4}$$

where $X$ represents either oxygen or argon. The agreement is good as may be seen from figure 2. In fact, the correspondence between values calculated from the second virial coefficient of oxygen and eq (1a) is better than one may justifiably expect from the principle of corresponding states.

### 3.2. High-Density Region

#### a. Isotherm Representation

The isotherms in the high-density region (see fig. 1) were represented by polynomials of the form

$$P = RT\rho + \sum_{i=1}^{n} A_i \rho^{i-1}, \tag{5}$$

where $A_1 = A_2 = 0$ for $T > T_c$ or $\rho < \rho_c$. No more than 3 coefficients were used for the isotherms below 60 K since these consisted of only 4 $P-\rho$ data points each. As many as 9 coefficients were necessary for the 146 K and 148 K isotherms (slightly above the critical temperature) to adequately represent the data. From 4 to 7 coefficients were needed to represent all of the remaining isotherms. The isotherms in the compressed liquid and vapor phases below the critical temperature were constrained to the corresponding saturation

density from reference [2] (see also Appendix). Above 138 K the isotherms were also fitted to the low density data in the virial region to provide a better match of the surfaces around the 6.0 mol/l isochore.

The standard deviation of the 381 experimental data points in the compressed liquid was only 0.005 percent while the 540 compressed vapor data points exhibit a larger deviation of 0.018 percent. The latter value is higher due mainly to the contribution from the isotherms just above the critical temperature where the deviations are much larger than over the rest of the surface.

#### b. Isochore Representation

Many calculations of thermodynamic properties require knowledge of the derivatives $(\partial P/\partial T)_\rho$ and $(\partial^2 P/\partial T^2)_\rho$. In the low-density region these derivatives may be calculated directly from eq (1). For densities above 6.0 mol/l it was first necessary to derive true isochores by calculating pressures at even density increments using the isotherm representations. Density increments of 0.5 mol/l were used for the 80 isochores between 5.5 and 45.0 mol/l. The true isochores were then represented using functions of the form

$$P=\sum_{i=1}^{n} A_i T^{(3-2i)}. \tag{6}$$

The number of terms [2] of eq (6) varied from 7 at the lowest density to 3 at the 45.0 mol/l isochore. The good fit of the isotherms was directly carried over in the correlation of these isochores.

## 4. Derived Properties

### 4.1. Densities of the Liquid at Freezing

Density calculations of the *PVT* surface below 56 K were obtained by extrapolating isobars computed from the isotherms between 56 K and 64 K. The density of the liquid in equilibrium with the solid derived from the intersections of these isobars with the melting curve, reference [3], was expressed as a function of either temperature or pressure by

$$\rho_{\text{melt }L}=\rho_t+0.208\ (T-T_t),\ \text{mol/l} \tag{7}$$

or

$$\rho_{\text{melt }L}=\rho_t+0.020\ P(\text{MN/m}^2). \tag{8}$$

A value of $44.86_2$ mol/l was used for the liquid density, $\rho_t$, at the triple point.

### 4.2. The Joule-Thomson Inversion Curve

Calculated points on the Joule-Thomson inversion curve are given in table 4. This curve is defined as the locus of points where the Joule-Thomson coefficient is equal to zero. This condition may be described in classical thermodynamics by the relationship

$$\frac{-T}{\rho^2}\left(\frac{\partial \rho}{\partial T}\right)_p=\frac{1}{\rho} \tag{9}$$

or more conveniently

$$T\left(\frac{\partial P}{\partial T}\right)_\rho=\rho\left(\frac{\partial P}{\partial \rho}\right)_T \tag{10}$$

Equation (10) was solved by an iterative technique using the isotherm derivatives, $(\partial P/\partial \rho)_T$, and the isochore derivatives, $(\partial P/\partial T)_\rho$, obtained from eqs (5) and (6), respectively. The computed pressure errors in table 4 are based on an assumed uncertainty of 1 percent in these derivatives. No published Joule-Thomson data for fluorine are available for comparison to values tabulated in table 4. However, a comparison with oxygen [11] and argon [12] using the theory of corresponding states based on critical parameters, is given in figure 3.

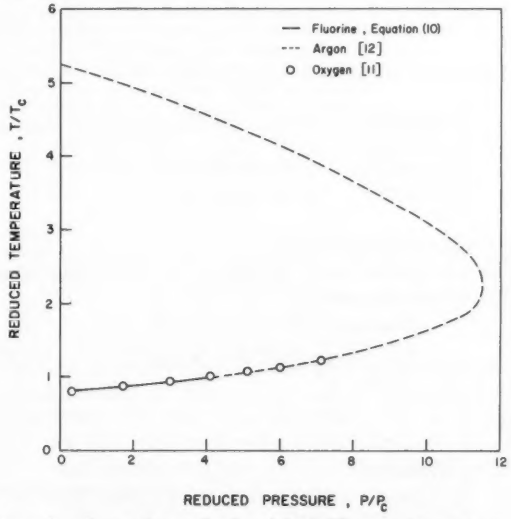


FIGURE 3. *Comparisons of reduced Joule-Thomson inversion curves of fluorine, oxygen, and argon.*

TABLE 4. *The Joule-Thomson inversion curve*

| $T$ | $P$ | Density | $\Delta P$ [a] |
|---|---|---|---|
| *K* | *MN/m²* | *Mol/l* | *MN/m²* |
| 118 | 2.732 | 32.615 | 0.19 |
| 120 | 4.340 | 32.411 | 0.21 |
| 122 | 6.092 | 32.250 | 0.22 |
| 124 | 7.649 | 32.058 | 0.23 |
| 126 | 9.288 | 31.895 | 0.23 |
| 128 | 10.861 | 31.727 | 0.25 |
| 130 | 12.373 | 31.556 | 0.25 |
| 132 | 13.824 | 31.381 | 0.26 |
| 134 | 15.278 | 31.214 | 0.26 |
| 136 | 16.583 | 31.024 | 0.28 |
| 138 | 17.980 | 30.864 | 0.27 |
| 140 | 19.155 | 30.664 | 0.26 |
| 142 | 20.811 | 30.573 | 0.31 |
| 144 | 21.668 | 30.322 | 0.31 |

[a] These estimated pressure errors are due to a 1 percent assumed uncertainty in either the isotherm or the isochore derivative.

[2] The coefficients of the 70 isotherms and the 80 isochores discussed above, may be obtained from the Cryogenic Data Center, National Bureau of Standards, Boulder, Colorado 80302.

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## 5. Appendix

Given below are correlations for different properties of fluorine as reported earlier. The number of significant figures given for the coefficients is not justified on the basis of the uncertainty of the data, but are presented to enable duplication of the calculated values.

*Vapor Pressure*

The following vapor pressure equation was presented in reference [2]:

$$\ln\left(\frac{P}{P_t}\right)=A_1X+A_2X^2+A_3X^3+A_4X(1-X)^{A_5} \tag{11}$$

where $X=(1-T_t/T)/(1-T_t/T_c)$ and

$A_1=$ 7.89592346 $\quad A_5=$ 1.4327
$A_2=$ 3.38765063 $\quad P_t=2.52\times10^{-4}$ MN/m²
$A_3=-1.34590196$ $\quad T_t=$ 53.4811 K
$A_4=$ 2.73138936 $\quad T_c=144.31$ K.

*Saturated Liquid Densities*

The saturated liquid densities, $\rho_l$, were described in [2] with the argument $Z=1-T/T_c$, as

$$\left(\frac{\rho_l-\rho_c}{\rho_c}\right)=B_1Z^{0.35}+\sum_{i=2}^{6}B_iZ^{i-1} \tag{12}$$

where

$B_1=$ 1.81881076 $\quad B_5=-1.01331503$
$B_2=8.75236491\times10^{-1}$ $\quad B_6=2.73840128\times10^{-1}$
$B_3=-8.50458910\times10^{-1}$ $\quad \rho_c=$ 15.10 mol/l
$B_4=$ 1.37284761 $\quad T_c=144.31$ K

*Saturated Vapor Density*

The saturated vapor densities, $\rho_g$, were reported by reference [2] as

$$\ln\left(\frac{\rho_g}{\rho_c}\right)=C_1\left(\frac{Z}{Z-1}\right)+C_2Z^{0.35}+\sum_{i=3}^{7}C_iZ^{i-2} \tag{13}$$

with the argument, $Z$, as given above. The coefficients are

$C_1=$ 4.85547085 $\quad C_3=-1.88066900\times10^{-1}$
$C_2=-1.96015519$ $\quad C_4=$ 6.21165939
$C_5=-2.29600897\times10^{1}$ $\quad C_7=-4.30650270\times10^{1}$
$C_6=4.69524623\times10^{1}$

*The Melting Curve*

Straty and Prydz [3] represented the pressures along the solid-liquid melting curve as

$$P=P_t+P_0\left[\left(\frac{T}{T_c}\right)^{c}-1\right] \tag{14}$$

where

$P_0=249.975$ MN/m²
$c=$ 2.1845,

and the other variables as defined above.

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# The Activity Coefficients of Hydrofluoric Acid in Water from 0 to 35 °C

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The mean stoichiometric activity coefficients of hydrofluoric acid in aqueous solutions have been calculated from measurements of electrolytic conductivity, the electromotive forces of galvanic cells without liquid junction, and the freezing-point depression. Values obtained from freezing-point depressions were converted to values for 25 °C using known values of the heats of dilution and apparent molal heat capacities of aqueous solutions of hydrofluoric acid of various concentrations. It is also shown that values for the concentrations of the various ionic species in hydrofluoric acid, namely, $H^+$, $F^-$, $HF_2^-$, and HF depend on the functions used to represent the ionic activity coefficients whereas values of the mean activity, $a_{H^+}a_{F^-}$, are independent of such functions. Values of the pH of various concentrations of hydrofluoric acid are given for temperatures of 0 to 35 °C; these, likewise, are nearly independent of activity-coefficient function used to obtain values for the ionic concentrations.

Key words: Activities of HF; equilibrium constant of HF dissociation; ionic concentrations in HF; pH values of HF.

During the critical evaluation of the activity coefficients of hydrofluoric acid under the National Standard Reference Data Program certain facts were uncovered that seemed worth presenting. These facts constitute this paper.

## 1. Dissociation of Hydrofluoric Acid

The degree of dissociation of hydrofluoric acid in aqueous solution is controlled by the two equilibria:

$$HF \rightleftarrows H^+ + F^- \tag{1}$$

and

$$HF_2^- \rightleftarrows HF + F^- \tag{2}$$

with the first one more significant at molal or molar concentrations below 0.001. The equilibrium constants for these reactions are given, respectively, by:

$$K = \frac{a_{H^+}a_{F^-}}{a_{HF}} = \frac{m_{H^+}m_{F^-}\gamma_{H^+}\gamma_{F^-}}{m_{HF}\gamma_{HF}} \tag{3}$$

and

$$k = \frac{a_{HF}a_{F^-}}{a_{HF_2^-}} = \frac{m_{HF}m_{F^-}\gamma_{HF}\gamma_{F^-}}{m_{HF_2^-}\gamma_{HF_2^-}} \tag{4}$$

where $a$, $m$, and $\gamma$ denote, respectively, the activity, molal concentration, and activity coefficient of the species denoted by the subscripts. Values of $K$ and $k$ may be determined from conductivity or emf measurements.

### 1.1. Conductivity Measurements

Values of $K$ and $k$ may be obtained from conductivity measurements as follows [1].[1] Let $y$ and $y_3$ be ratios, respectively, of the concentration unit of $F^-$ and $HF_2^-$ to the stoichiometric concentration, $C$, mol $kg^{-1}$, of HF and assume, as a start, that all activity coefficients are unity. Then,

$$K = \frac{Cy(y+y_3)}{(1-y-2y_3)} \cong Cy(y+y_3) \tag{5}$$

and

$$k = \frac{Cy(1-y-2y_3)}{y_3} \cong \frac{Cy}{y_3}. \tag{6}$$

For the simplified versions of eqs (5) and (6), $(1-y-2y_3)$ is set equal to unity.

Now the observed equivalent conductance, $\Lambda$, of HF is given approximately by:

$$\Lambda = y\Lambda_0 + y_3\lambda_0 \tag{7}$$

where $\Lambda_0$ is the sum of the limiting equivalent conductances of $H^+$ and $F^-$ and $\lambda_0$ is the sum of the limiting equivalent conductances of $HF_2^-$ and $H^+$. Solving the

[1] Figures in brackets indicate the literature references at the end of this paper.

simplified versions of eqs (5) and (6) for $y$ and $y_3$ and substituting in eq (7) gives:

$$\Lambda(1+C/k)^{1/2}=(\Lambda_0\sqrt{K})/\sqrt{C}+(\lambda_0\sqrt{K}/k)\sqrt{C}. \tag{8}$$

This equation may be converted to a linear form by multiplying by $\sqrt{C}$, adding and subtracting $C\Lambda_0\sqrt{K}/k$ to the right side, dividing by $(1+C/k)^{1/2}$, squaring both sides, and simplifying. This procedure [1] gives:

$$C\Lambda^2=\Lambda_0^2K+[2\lambda_0/\Lambda_0-1+(1-\lambda_0/\Lambda_0)^2/(1+k/C)]\Lambda_0^2KC/k. \tag{9}$$

The term $(1-\lambda_0/\Lambda_0)^2/(1+k/C)$ becomes negligible at low concentrations and approaches asymptotically the limit $(1-\lambda_0/\Lambda_0)^2$ at high concentrations. Hence, this term may be neglected when $\lambda_0/\Lambda_0$ is sufficiently close to unity to render $(1-\lambda_0/\Lambda_0)^2$ negligible with respect to $(2\lambda_0/\Lambda_0-1)$. Accordingly, eq (9) reduces to

$$C\Lambda^2=\Lambda_0^2K+C(2\Lambda_0\lambda_0-\Lambda_0^2)K/k. \tag{10}$$

Introducing corrections for the ionic activity coefficients,[2] $\gamma_c$, and changes in ionic mobility with concentration, $b$, in eq (10) leads to [1]

$$\left(\frac{\gamma_c\Lambda}{b}\right)^2\frac{C}{(1-\Lambda/\Lambda_0)}=\Lambda_0^2K+\frac{(2\Lambda_0\lambda_0-\Lambda_0^2)K}{k}\left(1-\frac{\Lambda}{\Lambda_0}\right)C, \tag{11}$$

where $(1-\Lambda/\Lambda_0)$ gives an approximation for the unionized portion of the solute. Furthermore, approximate values of $\gamma_c$ and $b$ are given, respectively, by:

$$\log\gamma_c=-A_c\sqrt{C\Lambda/\Lambda_0} \tag{12}$$

and

$$b=1-(B_1\Lambda_0+B_2)\Lambda_0^{-1}\sqrt{C\Lambda/\Lambda_0} \tag{13}$$

where $A_c$, $B_1$, and $B_2$ are constants given by:

$$A_c=\left(\frac{2\pi N}{1000}\right)^{1/2}\frac{e^3}{(4\pi\epsilon_0)^{3/2}2.302585\,k^{3/2}}\left(\frac{1}{T^{3/2}\epsilon^{3/2}}\right) \tag{14}$$

$$B_1=\frac{e^2}{6\epsilon kT(1+\sqrt{0.5})}\left(\frac{8\pi Ne^2}{(4\pi\epsilon_0)^2 1000\epsilon kT}\right)^{1/2} \tag{15}$$

$$B_2=\frac{F^2}{3\pi\eta N}\left(\frac{8\pi Ne^2}{(4\pi\epsilon_0)2\,1000\epsilon kT}\right)^{1/2} \tag{16}$$

in which $N$ is Avogadro's constant ($6.02252\times10^{26}$ kmol$^{-1}$), $e$ is the elementary charge ($1.60210\times10^{-19}C$), $\mathbf{k}$ is Boltzmann's constant ($1.38054\times10^{-23}$ J/K), $T$ is the Kelvin temperature, $\epsilon$ is the dielectric constant of water, $\eta$ is the viscosity of water, and $\epsilon_0$ is the permittivity of free space ($8.85417\times10^{-12}C^2J^{-1}m^{-1}$). Using these values, concentrations are expressed in kmol m$^{-3}$ and equivalent conductances in $m^2\Omega^{-1}$. Numerical values, however, remain the same as normally used in the cgs system of units.

A plot of the left side of eq (11) against $c(1-\Lambda/\Lambda_0)$ gives a straight line. The intercept at $c(1-\Lambda/\Lambda_0)=0$ gives $\Lambda_0^2K$ and the slope of the line the value of $(2\Lambda_0\lambda_0-\Lambda_0^2)K/k$. Accordingly $K$ and $k$ may be evaluated if values of $\Lambda_0$ and $\lambda_0$ are known.

Data on the conductivity of hydrofluoric acid at 25 °C have been reported by Deussen [2], Fredenhagen and Wellmann [3], Thomas and Maass [4], Ellis [5], and Erdey-Grúz, Majthényi, and Kugler [6]. Thomas and Maass reported their values to only one significant figure and the data of Erdey-Grúz et al. were lower than those of the others. The data of Deussen, Fredenhagen and Wellmann, and Ellis agreed to within 0.1 in the equivalent conductance and were accepted. Measurements of $\Lambda$ were made at 16 and 20 °C by Roth [7] and Hill and Sirkar [8]. The data of Hill and Sirkar were very much lower than those of Roth and were inconsistent with the data obtained by other experimenters at other temperatures. Deussen [2] and Hill and Sirkar [8] made measurements at 0 °C; the data of the latter showed erratic changes with concentration. The data of Hill and Sirkar at 0, 16, and 20 °C were, therefore, not considered.

Since HF shows complex dissociation, $\Lambda_0$ values could not be obtained from $\Lambda$ values on extrapolation to $c=0$. Accordingly, $\Lambda_0$ for HF at 25 °C was obtained from the known values of $\Lambda_0$ of 126.39, 105.43, and 426.06 $\Omega^{-1}$ m kequiv$^{-1}$, respectively, for NaCl [9], NaF [6], and HCl [10] using the Kohlrausch law of the independent migration of ions (the literature data, were, in each case, converted to absolute ohms using the factor: 1 international ohm = 1.000495 absolute ohms); this procedure gave 405.10 $\Omega^{-1}$ m kequiv$^{-1}$ for $\Lambda_0$ for HF at 25 °C. Wooster [1] gave 225 and 404 $\Omega^{-1}$ m kequiv$^{-1}$ for $\Lambda_0$ at 0 °C and 25 °C, respectively. Using the ratio 405.10/404 (at 25 °C), his value at 0 °C becomes 225.69 $\Omega^{-1}$ m kequiv$^{-1}$. From a linear plot of $\Lambda_0$ against $1/T$ 354.29, 365.85, and 377.26 $\Omega^{-1}$ m kequiv$^{-1}$ were obtained for $\Lambda_0$ at 16, 18, and 20 °C, respectively. Wooster [1] obtained 437 and 275.4 $\Omega^{-1}$ m kequiv$^{-1}$ for $\lambda_0$ at 25 °C and 0 °C, respectively. On converting to absolute ohms and from a $(\lambda_0-1/T)$ plot, 276.15, 383.08, 395.62, 407.99, and 438.19 $\Omega^{-1}$ m kequiv$^{-1}$ were obtained for $\lambda_0$ at 0, 16, 18, 20, and 25 °C, respectively [11]. Using these values for $\Lambda_0$ and $\lambda_0$, known values of $A_c$ [11] and $B_1$ [10] and $B_2$ [10] and data for $\Lambda$ cited above, eq (11) was used to obtain the values of $K$ and $k$ given in table 1. Plots of $(\gamma c\Lambda/b)^2(c/(1-\Lambda/\Lambda_0))$ against $c(1-L/L_0)$ are shown in figure 1. Line $A$ is obtained if no corrections are made for activity coefficients or changes in ionic mobilities with concentration, i.e., $(\gamma/b)^2$ is unity. Line $B$ is obtained if corrections are made for activity coefficients and line $C$ if both types of corrections are made. Values of $K$ and $k$ are obtained from line $C$. Plots at the other temperatures were similar to that of figure 1. Although the concentration unit used in the

[2] Corrections for ionic activity coefficients are introduced by using $K/\gamma_c$ for $K$; no correction is needed for $k$ since the activity coefficients cancel in eq (4). Corrections for the ionic mobility are introduced by using $\Lambda=b(\gamma\Lambda_0+\gamma_3\lambda_0)$ instead of the approximate eq (7) which is based on the limiting equivalent conductances.

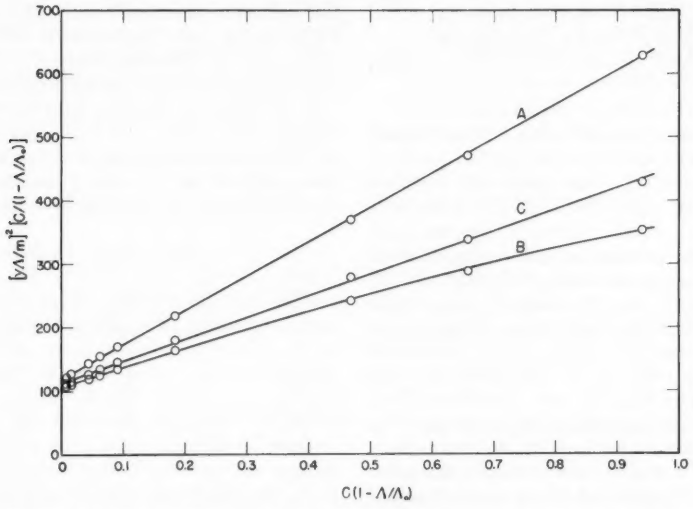


FIGURE 1. *Plots used to obtain values for* K *and* k *governing the dissociation of* HF.

A. No corrections made for activity coefficients or changes in ionic mobilities with concentration.
B. Corrections made for activity coefficients.
C. Corrections made for activity coefficients and changes in ionic mobilities with concentration.

TABLE 1. *Constants,* K *and* k, *for the equilibria governing the dissociation of hydrofluoric acid* [a]

| $t$ | $\Lambda_0$ | $\lambda_0$ | $A_c$ | $B_1$ | $B_2$ | $K$ | $k$ |
|---|---|---|---|---|---|---|---|
| °C | $\Omega^{-1}$ m equiv$^{-1}$ | $\Omega^{-1}$ m equiv$^{-1}$ | $m^{3/2}$ kmol$^{-1/2}$ | $m^{3/2}$ kmol$^{-1/2}$ | $\Omega^{-1}$ $m^{3/2}$ kmol$^{-1/2}$ | mol kg$^{-1}$ | mol kg$^{-1}$ |
| 0 | 255.69 | 276.15 | 0.4918 | 0.2211 | 29.82 | 0.00109 | 0.413 |
| 16 | 354.29 | 383.08 | .5038 | .2266 | 48.48 | .000782 | .362 |
| 18 | 365.85 | 395.62 | .5054 | .2272 | 51.06 | .000755 | .355 |
| 20 | 377.26 | 407.99 | .5072 | .2280 | 53.72 | .000731 | .347 |
| 25 | 405.10 | 438.19 | .5116 | .2300 | 60.64 | .000684 | .381 |

[a] On the SI the unit for $K$ and $k$ is kmol m$^{-1}$.

conductivity measurements was mol l$^{-1}$, because of the experimental uncertainties it is assumed here that $K$ and $k$ can be expressed in units of mol kg$^{-1}$.

Wooster [1] obtained 0.000689 and 0.320 mol l$^{-1}$ for $K$ and $k$, respectively, using older conductance data in international ohms. Davies and Hudleston [12], by combining data on the anodic transference number and the equivalent conductances of HF, obtained 0.213 mol l$^{-1}$ for $k$ at 25 °C. However, they made no corrections for activity coefficients or the variation of the ionic mobilities with concentration. When these corrections are made, their data yield 0.333 mol l$^{-1}$, if the value of $K$, obtained here, is used. This value is still considerably lower than that obtained with later conductance data.

### 1.2. Electromotive Force Measurements

$K$ and $k$ for HF may also be obtained from the electromotive forces (emfs) of cells of the type:

$$\mathrm{Pb-Hg|PbF_2}(s)\,\mathrm{|HF}(m_1),\ \mathrm{NaF}(m_2)\,\mathrm{|H_2}(g),\ \mathrm{Pt} \qquad \text{(A)}$$

used by Broene and DeVries [13] where $s$ = solid, $m$ = molality, $g$ = gas, and the vertical lines indicate the interface between distinct phases. Broene and DeVries used a 5 percent amalgam. The emf of this cell, as a function of $m$, is given by:

$$E = E^0 + \frac{2.303RT}{2F}\log m_{H^+} m_{F^-} \gamma_{H^+}\gamma_{F^-} \qquad (17)$$

$$E = E^0 + \frac{2.303RT}{2F}\log m_{H^+}(m_2 + m_{H^+} - m_{HF_2^-})\gamma_{H^+}\gamma_{F^-} \qquad (18)$$

or

$$E = E^0 + \frac{2.303RT}{2F}\log h \qquad (19)$$

where $h$ denotes $m_{H^+}\ (m_2 + m_{H^+} - m_{HF_2^-})\ \gamma_{H^+}\ \gamma_{F^-}$ and $E^0$ denotes the standard potential of the Pb − Hg (5%), $PbF_2$, F- electrode; this value was determined at 15 °C (0.3346 V), 25 °C (0.3445 V), and 35 °C (0.3551 V) by Ivett and DeVries [14] (their values were converted here to absolute volts using the factor: 1 international volt = 1.0003384 absolute volts). Now the two equilibrium constants, as given by eqs (3) and (4) may be expressed as:

$$K = \frac{m_{H^+}(m_2 + m_{H^+} - m_{HF_2^-})\gamma_{H^+}\gamma_{F^-}}{(m_1 - m_{H^+} - m_{HF_2^-})\gamma_{HF}} = \frac{h}{m_1 - m_2 - 2m_{H^+} + h/(m_{H^+}\gamma_{H^+}\gamma_{F^-})} \qquad (20)$$

$$k = \frac{(m_1 - m_{H^+} - m_{HF_2^-})\ (m_2 + m_{H^+} - m_{HF_2^-})\gamma_{H^+}\gamma_{F^-}}{m_{HF_2^-}\gamma_{HF_2^-}}$$



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$$= \frac{\left(m_1 - m_2 - 2m_{H^+} + \frac{h}{m_{H^+}\gamma_{H^+}\gamma_{F^-}}\right)\left(\frac{h}{m_{H^+}\gamma_{H^+}\gamma_{F^-}}\right)}{m_2 - m_{H^+} - h/(m_{H^+}\gamma_{H^+}\gamma_{F^-})}. \quad (21)$$

In the second expression of eq (20), $\gamma_{HF}$ is taken equal to 1 while in the second expression of eq (21), $\gamma_{HF}\gamma_{F^-}/\gamma_{HF_2^-}$ is taken equal to 1. For each acid-salt solution there are two equations like (20) and (21) with four unknowns: $K$, $k$, $m_{H^+}$, and $\gamma_{H^+}\gamma_{F^-}$. Broene and DeVries [13] reduced the number of unknowns to three by assuming that the mean activity coefficient of NaF in the HF–NaF solutions was the same as that found by Ivett and DeVries [14] for NaF alone. Broene and DeVries then inserted various values of $m_{H^+}$ (obtained approximately from eq (18)) in eq (20) and (21) and calculated the corresponding $K$ and $k$ values. They then plotted the values of $K$ against the corresponding $k$. Since they had studied four HF–NaF mixtures they had four straight lines. $K$ and $k$ were given by the point where the four lines intersected. The same process could be accomplished by iteration, using various values of $m_{H^+}$ until the same value is obtained for $K$ and for $k$ at the concentrations studied.

Broene and De Vries [13] obtained 0.000793, 0.000671, and 0.000564 mol kg$^{-1}$ for $K$ at 15, 25, and 35 °C, respectively, and 0.254, 0.259, and 0.231 mol kg$^{-1}$ for $k$ at 15, 25, and 35 °C, respectively (they actually gave values for the reciprocal for $k$). Their values for $K$ agree closely with the conductivity data but their $k$ value is lower than that obtained from conductivity data. However, in treating their data they assumed that the solubility of $PbF_2$ in HF–NaF was negligible and that the liquid-junction potential between the solution saturated with $PbF_2$ and the solution not so saturated could be neglected. It is for these reasons that the conductivity values for $K$ and $k$ are considered preferable.

## 2. Activities and Activity Coefficients of HF

The mean ionic activity, $(a_\pm)_i$, and the mean ionic activity coefficient of HF are given, respectively, by:

$$(a_{H^+}a_{F^-})_i^{1/2} = (a_\pm)_i = (\gamma_\pm)(m_\pm)_i \quad (22)$$

and

$$(\gamma_{H^+}\gamma_{F^-})_i^{1/2} = \frac{(a_\pm)_i}{(m_{H^+}m_{F^-})_i^{1/2}} = \frac{(a_\pm)_i}{(m_\pm)_i}. \quad (23)$$

Now $(m_\pm)_i = (m_\pm)_s$, where $s$ = stoichiometric, only if HF were completely dissociated.

Broene and DeVries [13] calculated the activity coefficients of various stoichiometric concentrations of HF from measurements of the emf of the cell:

$$\text{Pb—Hg} \mid PbF_2(s) \mid HF(m) \mid H_2(g), \text{Pt} \quad (B)$$

where the symbols have the same significance as given above. In this case Broene and DeVries corrected for the solubility of $PbF_2$ in HF [15, 16, 17] and calculated the liquid-junction potential for the junction of the solution saturated with $PbF_2$ and the one free of $PbF_2$ using the Henderson [18] equation. The $E^0$ values for the Pb–Hg, $PbF_2$, $F^-$ electrode, determined by Ivett and DeVries, and listed above were used.

It is most interesting that Broene and DeVries obtained their values of the activity coefficients of HF by first calculating the activities of $H^+$ and $F^-$ using their values for $K$ and $k$ and the Güntelbrug's [19] modification of Debye-Hückel equation

$$\log \gamma_\pm = -A\sqrt{I}/(1+\sqrt{I}) \quad (24)$$

for the activity coefficient. In eq (24), $I$ represents the ionic strength; they did not state the value of $A$ they used. They reported their activity coefficients as stoichiometric ones which they calculated from $\gamma = (a_{H^+}a_{F^-})^{1/2}/m$ where $m$ is the stoichiometric molality. Actually, they did not need to use this procedure involving values of $K$ and $k$, since the stoichiometric activity coefficients may be calculated directly from the observed emfs of cell (B) using the equation:

$$E = E^0 + \frac{2.303RT}{2F}\log a_{H^+}a_{F^-} + E_j \quad (25)$$

or

$$E = E^0 + \frac{2.303RT}{2F}\log m_{H^+}\,(m_{F^-} + m')\,\gamma_{H^+}\gamma_{F^-} + E_j \quad (26)$$

where $m'$ = molality of the fluoride ion arising from the solubility of $PbF_2$ in HF and $E_j$ denotes the liquid-junction potential. Values of $(\gamma_{H^+}\gamma_{F^-})^{1/2}$ or $\gamma_\pm$, obtained directly from the emfs of cell B by eq (26), with and without Henderson [18] corrections for $E_j$, are given, respectively, in the second and third columns of table 2 and compared with those calculated by Broene and DeVries from their $K$ and $k$ values. In obtaining the direct emf values, the values were read from a curve of $\gamma_\pm$ (obtained from the emfs) versus $\sqrt{m_{HF}}$, neglecting $m'$ in the plot; if $m'$ were used agreement between calculated and observed $\gamma_\pm$'s was obtained only above 0.03 molal. It will be noted that the Henderson equation gives an overcorrection for $E_j$ for the dilute solutions. Hamer and Acree [20] have shown that this is frequently the case; in the Henderson equation concentrations rather than activities are used. On the other hand, the direct values obtained from the emf data without $E_j$ corrections agree closely with those calculated by Broene and DeVries as well as those calculated from conductivity data. The close agreement between the data of Broene and DeVries and the conductivity data shows that the value of $\gamma_\pm$ is insensitive to the value of $k$ (the emf and conductivity values for $K$ agree closely whereas the $k$ values differ by about 30 percent); this follows since $\gamma_\pm$ is for the $H^+$ and $F^-$ ions and does not include the activity coefficient of the $HF_2^-$ ion.

Anthony and Hudleston [21] measured the freezing-point depression of HF solutions from 0.025 to 4.14 molal and Parker [22] gave values for the apparent

TABLE 2. *Comparison of stoichiometric mean activity coefficients of hydrofluoric acid at 25 °C obtained from electromotive force, conductivity, and freezing point and heat of dilution data.*

| $m$ | Electromotive Force | | | Conductivity [c] | Freezing point and heats of dilution |
|---|---|---|---|---|---|
| | Emf with $E_j$ corrections [a] | Emf without $E_j$ corrections [a] | Broene and DeVries [b] | | |
| *mol/kg $H_2O$* | | | | | |
| 0.001 | 0.822 | 0.543 | 0.544 | 0.547 | 0.542 |
| .002 | .658 | .449 | [d](0.431) | .433 | .455 |
| .003 | .557 | .387 | .371 | .373 | (0.406) |
| .005 | .436 | .313 | .300 | .304 | .340 |
| .007 | .365 | .264 | (0.263) | .264 | (0.300) |
| .01 | .295 | .219 | .224 | .227 | .259 |
| .02 | .195 | .162 | (0.166) | .166 | .188 |
| .03 | .157 | .138 | .136 | .136 | (0.154) |
| .05 | .119 | .108 | .106 | .108 | .116 |
| .10 | .079 | .076 | .077 | .0778 | .079 |
| .20 | .055 | .055 | (0.055) | .0554 | .053 |
| .30 | .045 | .045 | .044 | .0450 | .043 |
| .50 | .035 | .035 | [e].031 | .0351 | .033 |
| 1.0 | .025 | .025 | .024 | .0248 | .024 |
| 2.0 | ..... | ..... | ..... | .0174 | .0178 |
| 3.0 | ..... | ..... | ..... | .0141 | .0147 |
| 4.0 | ..... | ..... | ..... | .0121 | .0131 |

[a] All values were read from a smooth curve of emf data versus $m^{1/2}$.
[b] Using the $K$ and $k$ values of Broene and De Vries [13].
[c] Using the $K$ and $k$ values obtained herein.
[d] Values in parentheses were read from a smooth curve of data versus $m^{1/2}$.
[e] Apparently in error; 0.034 is a better value.

molal heat capacity and the heats of dilution of HF from 0 to 22.753 molal. The stoichiometric osmotic coefficient, $\phi$, of HF at 25 °C may be obtained from these data by the eqs [23, 24, 25]:

$$\nu\lambda m\phi = \left(1 + \frac{\bar{L}_1}{\Delta H_f^0}\right)\theta + \left(1/T_f - \frac{\Delta C_f^0}{2\Delta H_f^0} + \frac{\bar{L}_1}{T_f \Delta H_f^0} - \frac{\bar{J}_1}{2\Delta H_f^0}\right)\theta^2 + \left(1/T_f^2 - \frac{2\Delta C_p^0}{3T_f\Delta H_f^0} + \frac{\Delta b}{6\Delta H_f^0} + \frac{\bar{L}_1}{T_f^2\Delta H_f^0} - \frac{2\bar{J}_1}{3T_f\Delta H_f^0}\right)\theta^3 + \ldots . \quad (27)$$

where

$\nu$ = number of ions in one molecule of solute = 2
$\lambda$ = molal freezing-point depression = 1.860 ± 0.001 K/kg mol$^{-1}$ for $H_2O$
$m$ = molality
$\bar{L}_1$ = relative partial molal enthalpy of solvent at $T$
$\Delta H_f^0$ = heat of fusion of pure water = 6009.48 J mol$^{-1}$ (1436.3 cal mol$^{-1}$)
$\theta$ = freezing-point depression = $T_f - T$
$T_f$ = freezing point of pure solvent; 273.15 K for $H_2O$.
$\Delta C_f^0 = \Delta\bar{C}_f - \bar{J}_1$, where $\Delta\bar{C}_f = \Delta a + \Delta b T_f = (\Delta\bar{C}_p)_{T_f}$ where $\Delta\bar{C}_p$ is the difference between the partial molal heat capacity of the solvent in the solution and the molal heat capacity of the solid solvent.
$\bar{J}_1$ = relative partial molal heat capacity of solvent at constant pressure at $T$
$b$ = coefficient in $\Delta\bar{C}_f = \Delta a + \Delta b T_f$.

The mean activity coefficient of HF is then obtained from $\phi$ by the relation:

$$\ln\gamma = (\phi - 1) + \int_0^m (\phi - 1) d\ln m. \quad (28)$$

Values of $\gamma$ so calculated are given in the last column of table 2. The agreements with the emf and conductivity data are generally good when one considers the uncertainties in the heat data for HF.

## 3. Ionic and Molecular Species in HF

Broene and DeVries in calculating $\gamma_\pm$ from $(a_{H^+}a_{F^-})^{1/2}/m$ used the Güntelberg equation for ionic activity coefficients in obtaining values for $a_{H^+}$ and $a_{F^-}$ from the emf data. One may ask, therefore, if their values for $\gamma_\pm$ did not depend on this choice and would be different if another expression had been used for the ionic activity coefficient. The concentrations but not the activities of the ionic species would differ, since from eq (25)

$$\log a_{H^+}a_{F^-} = \frac{E - E^0 - E_j}{2.303RT/2F}. \quad (29)$$

$a_{H^+}a_{F^-}$ is a constant for each stoichiometric concentration of HF. This may be shown in another way, as follows:

According to the equilibria given by eq (3) and (4), values of $m_{H^+}$, $m_{F^-}$, $m_{HF_2^-}$ and $m_{HF}$ and the corresponding ionic activities can be obtained from $K$ and $k$ only by selecting some function to represent the activity coefficients, $\gamma_{H^+}$, $\gamma_{F^-}$, $\gamma_{HF_2^-}$, and $\gamma_{HF}$ (in accord with convention, the last one may be taken equal to 1). In other words, values of $m_{H^+}$, etc., for any stoichiometric molality, $m$, of HF differ for each function selected to represent the $\gamma$'s. On the other hand, $(a_{H^+}a_{F^-})$ will be the same, regardless of the function selected for the $\gamma$'s, since $(a_{H^+}a_{F^-})^{1/2} = K^{1/2}$.

To illustrate, seven different theoretical equations [11], namely, those of Debye-Hückel limiting law, Güntelberg, extended Güntelberg, Davies, Scatchard, extended Scatchard, and Bjerrum are used to calculate the molalities of all species in HF. In all of these calculations values for the ionic strength, $I$, are needed. The ionic strength is given by

$$I = (m_{H^+} + m_{F^-} + m_{HF_2^-})/2 = my + my_3. \quad (30)$$

Combining eqs (5) and (6), eq (31) results:

$$\frac{K(1-y-2y_3)}{m\gamma^2} = y^2\left[1 + \frac{m}{k/(1-y-2y_3)}\right]. \quad (31)$$

The activity coefficient term is evaluated:

$$\gamma = \text{one of 7 functions of } I \text{ or } my + my_3. \quad (32)$$

Values of $y$, or $m_{F^-}/m$, are obtained from eqs (31) and (32) by iteration. Iteration is necessary since $\gamma$ depends on an a priori knowledge of $y$. As a start $y$ is assumed to be unity in the $\gamma$ function; $y$ thus obtained from eq (31) is then substituted in eq (32) to get a new value of $\gamma$ which is then used in eq (31) to get a new value of $y$ and so on. Values of $y_3$, or $m_{HF_2^-}/m$ are then obtained from eq (6) and $m_{H^+}$ from $y + y_3$. The molality of the undissociated HF is then obtained from values of $y_3$, $y + y_3$, and $m$. In table 3, these values are given for $m = 1$, for illustration. It will be noted that the values of $H^+$, $F^-$, etc., differ for each $\gamma$ function but that all $\gamma$ functions lead to the same value for the product: $(m_{H^+}m_{F^-})^{1/2}$ $(\gamma_{H^+}\gamma_{F^-})^{1/2}$ or $a_\pm$. Furthermore, each one equals $a_\pm$ as obtained from $(a_{H^+}a_{F^-})^{1/2}/m$ obtained directly from the emf measurements. These same principles obtain for other stoichiometric concentrations of HF, and for brevity are not given here. It is important to note that stoichiometric activity coefficients of HF given by $(a_{H^+}a_{F^-})^{1/2}/m$ are independent of a choice of $\gamma$ function.

Another interesting fact is that the pH of the solution as given by $\log m_{H^+}\gamma_{H^+} = \log m_{H^+}\gamma_\pm$ is practically independent of the $\gamma$ function selected. This comes about from the ionic equilibria for HF and is quite different from what would be obtained for a completely dissociated acid, such as HCl. To illustrate, the pH of 1 molal HCl as calculated by the seven theoretical $\gamma$ functions is given in the last column of table 3. It is evident that the spread in pH values for HCl is 0.523, whereas for HF it is only 0.003.

For completeness, $\gamma_\pm$, $a_\pm$, pH, and ionic and molecular (HF) concentrations for various stoichiometric concentrations of HF are given in table 4. Also, for completeness, $\gamma_\pm$ and pH of various stoichiometric concentrations of HF were calculated at 0 °C using the $K$ and $k$ values listed in table 1. These quantities are given in tables 5 and 6, respectively. In these tables data are also listed for temperatures between 0 and 25 °C and at 30 and 35 °C. Values between 0 and 25 °C were obtained by interpolation while those above 25 °C were obtained by extrapolation. Values of $\gamma_\pm$ in parentheses were obtained from emf measurements by Broene and DeVries [13] and are given for comparison. Also values of the concentration of the ionic and molecular species in various stoichiometric concentrations of HF, as calculated using the limiting law of Debye and Hückel, are given for 0 °C and 25 °C in tables 7 and 8, respectively. Values at intermediate temperatures may be obtained by interpolation. These are relative values since some function other than the Debye-Hückel limiting law for activity coefficients would give a better estimate of their magnitude (see table 3).

TABLE 3. *Molalities of the ionic species and undissociated* HF *in 1 molal (stoichiometric)* HF *at 25 °C, including data on ionic strength, mean ionic activity coefficient, mean ionic activity, and* pH *based on various theoretical functions of the ionic activity coefficient,* $\gamma_{H^+}\gamma_{F^-}$

| Activity coefficient function | $m_{H^+}$ | $m_{F^-}$ | $m_{HF_2^-}$ | $m_{HF}$ | $I$ | $\gamma_\pm = (\gamma_{H^+}\gamma_{F^-})^{1/2}$ | $a_\pm$ | pH | pH (1 $m$ HCl) |
|---|---|---|---|---|---|---|---|---|---|
| Debye-Hückel | 0.06059 | 0.01807 | 0.04252 | 0.8969 | 0.06059 | 0.7486 | 0.0248 | 1.343 | 0.292 |
| Güntelberg (ext.)[a] | .05726 | .01700 | .04026 | .9025 | .05726 | .7964 | .0248 | 1.341 | .590 |
| Güntelberg | .05723 | .01699 | .04024 | .9025 | .05723 | .7969 | .0248 | 1.341 | .593 |
| Bjerrum | .05680 | .01685 | .03995 | .9033 | .05680 | .8034 | .0248 | 1.341 | .630 |
| Davies | .05647 | .01675 | .03973 | .9038 | .05647 | .8085 | .0248 | 1.340 | .815 |
| Scatchard (ext.)[a] | .05615 | .01665 | .03951 | .9043 | .05615 | .8135 | .0248 | 1.340 | .687 |
| Scatchard | .05611 | .01663 | .03948 | .9044 | .05611 | .8142 | .0248 | 1.340 | .690 |

[a]Extended or modified equation.

TABLE 4. *Molalities of the ionic species and undissociated* HF *in various stoichiometric molalities of* HF *at 25 °C, including data on ionic strength, mean ionic activity coefficient, mean ionic activity, and* pH *based on the Debye-Hückel limiting law for ionic activity coefficients*

| $C$ | $m_{H^+}$ | $m_{F^-}$ | $m_{HF_2^-}$ | $m_{HF}$ | $I$ | $\gamma_\pm = (\gamma_{H^+}\gamma_{F^-})^{1/2}$ | $a_\pm$ | $a_\pm$ (Broene & DeVries) | pH |
|---|---|---|---|---|---|---|---|---|---|
| 0.001 | 0.000562 | 0.000562 | 0.00000064 | 0.000437 | 0.000562 | 0.9725 | 0.000547 | 0.000544 | 3.26 |
| .002 | .000899 | .000897 | .00000258 | .001098 | .000899 | .9653 | .000867 | ..... | 3.06 |
| .003 | .001167 | .001161 | .00000557 | .001828 | .001167 | .9606 | .00112 | .00113 | 2.95 |
| .005 | .001602 | .001588 | .00001410 | .003384 | .001602 | .9540 | .00152 | .00150 | 2.82 |
| .007 | .001963 | .001938 | .00002549 | .005011 | .001963 | .9492 | .00185 | ..... | 2.73 |
| .01 | .002428 | .002381 | .00004702 | .007525 | .002428 | .9437 | .00227 | .00224 | 2.64 |
| .02 | .003649 | .003501 | .0001489 | .01620 | .003649 | .9314 | .00333 | ..... | 2.47 |
| .05 | .006236 | .005602 | .0006342 | .04313 | .006236 | .9113 | .00539 | .0053 | 2.25 |
| .10 | .009696 | .007869 | .001827 | .08848 | .009696 | .8906 | .00778 | .0077 | 2.06 |
| .20 | .01556 | .01058 | .004983 | .1795 | .01556 | .8636 | .0111 | .0132 | 1.87 |
| .50 | .03202 | .01467 | .017348 | .4506 | .03202 | .8102 | .0176 | .0155 | 1.59 |
| 1.0 | .06059 | .01807 | .04252 | .8969 | .06059 | .7486 | .0248 | .0240 | 1.34 |
| 2.0 | .1255 | .02221 | .1033 | 1.771 | .1255 | .6593 | .0348 | ..... | 1.08 |
| 3.0 | .2016 | .02558 | .1760 | 2.622 | .2016 | .5897 | .0423 | ..... | 0.93 |
| 4.0 | .2901 | .02886 | .2612 | 3.449 | .2901 | .5308 | .0486 | ..... | 0.81 |

TABLE 5. *Stoichiometric mean activity coefficients of aqueous solutions of hydrofluoric acid*

| $m$ | $t$, °C | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 5 | 10 | 15 | 15 | 18 | 20 | 25 | 25 | 30 | 35 | 35 |
| *mol/kgH₂O* | | | | | | | | | | | | |
| 0.001 | 0.624 | 0.609 | 0.593 | 0.578 | [a](0.573) | 0.569 | 0.562 | 0.547 | (0.544) | 0.532 | 0.516 | (0.515) |
| .002 | .505 | .491 | .477 | .462 | ..... | .454 | .448 | .434 | ..... | .419 | .405 | ..... |
| .003 | .440 | .427 | .413 | .400 | (0.395) | .393 | .387 | .373 | (0.371) | .360 | .347 | (0.347) |
| .005 | .366 | .354 | .342 | .328 | (0.320) | .322 | .316 | .304 | (0.300) | .292 | .280 | (0.280) |
| .007 | .320 | .309 | .297 | .287 | ..... | .280 | .276 | .264 | ..... | .253 | .241 | ..... |
| .01 | .276 | .266 | .256 | .247 | (0.241) | .241 | .237 | .227 | (0.224) | .217 | .207 | (0.208) |
| .02 | .205 | .197 | .190 | .182 | ..... | .177 | .174 | .167 | ..... | .159 | .152 | ..... |
| .05 | .134 | .129 | .124 | .118 | (0.115) | .115 | .113 | .108 | (0.106) | .102 | .0976 | (0.097) |
| .10 | .0968 | .0930 | .0892 | .0854 | (0.083) | .0831 | .0816 | .0778 | (0.077) | .0740 | .0702 | (0.070) |
| .20 | .0690 | .0665 | .0635 | .0610 | ..... | .0595 | .0580 | .0555 | ..... | .0530 | .0500 | ..... |
| .50 | .0438 | .0420 | .0404 | .0386 | (0.034) | .0376 | .0370 | .0352 | (0.031) | .0334 | .0318 | (0.028) |
| 1.0 | .0309 | .0297 | .0285 | .0272 | (0.026) | .0266 | .0260 | .0248 | (0.024) | .0236 | .0224 | (0.022) |
| 2.0 | .0217 | .0208 | .0200 | .0191 | ..... | .0186 | .0183 | .0174 | ..... | .0165 | .0157 | ..... |
| 3.0 | .0175 | .0168 | .0161 | .0155 | ..... | .0151 | .0148 | .0141 | ..... | .0134 | .0127 | ..... |
| 4.0 | .0150 | .0144 | .0139 | .0133 | ..... | .0130 | .0128 | .0122 | ..... | .0116 | .0111 | ..... |

[a] Values in parentheses, Broene & DeVries [13].

TABLE 6. pH *of aqueous solutions of hydrofluoric acid*

| $m$ \ $t$, °C | 0 | 5 | 10 | 15 | 18 | 20 | 25 | 30 | 35 |
|---|---|---|---|---|---|---|---|---|---|
| 0.001 | 3.21 | 3.22 | 3.23 | 3.24 | 3.25 | 3.25 | 3.26 | 3.27 | 3.29 |
| .002 | 2.99 | 3.01 | 3.02 | 3.03 | 3.04 | 3.05 | 3.06 | 3.08 | 3.09 |
| .003 | 2.88 | 2.89 | 2.91 | 2.92 | 2.93 | 2.94 | 2.95 | 2.97 | 2.98 |
| .005 | 2.74 | 2.75 | 2.77 | 2.78 | 2.79 | 2.80 | 2.82 | 2.83 | 2.85 |
| .007 | 2.65 | 2.66 | 2.68 | 2.70 | 2.71 | 2.71 | 2.73 | 2.75 | 2.76 |
| .01 | 2.56 | 2.57 | 2.59 | 2.61 | 2.62 | 2.62 | 2.64 | 2.66 | 2.67 |
| .02 | 2.38 | 2.40 | 2.42 | 2.43 | 2.44 | 2.45 | 2.47 | 2.49 | 2.51 |
| .05 | 2.15 | 2.17 | 2.19 | 2.21 | 2.22 | 2.23 | 2.25 | 2.26 | 2.28 |
| .10 | 1.97 | 1.99 | 2.01 | 2.03 | 2.04 | 2.05 | 2.06 | 2.08 | 2.10 |
| .20 | 1.78 | 1.80 | 1.82 | 1.84 | 1.85 | 1.85 | 1.87 | 1.89 | 1.91 |
| .50 | 1.50 | 1.52 | 1.54 | 1.55 | 1.56 | 1.57 | 1.59 | 1.60 | 1.62 |
| 1.0 | 1.26 | 1.28 | 1.30 | 1.31 | 1.32 | 1.33 | 1.34 | 1.36 | 1.38 |
| 2.0 | 1.01 | 1.02 | 1.04 | 1.05 | 1.06 | 1.07 | 1.08 | 1.10 | 1.11 |
| 3.0 | 0.85 | 0.87 | 0.90 | 0.91 | 0.91 | 0.91 | 0.93 | 0.94 | 0.95 |
| 4.0 | .74 | .76 | .77 | .78 | .79 | .80 | .81 | .83 | .84 |

TABLE 7. *Relative ionic and molecular species in aqueous solutions of hydrofluoric acid at 0 °C*
(based on Debye-Hückel limiting law for activity coefficients)

| $m$ | $H^+$ | $F^-$ | $HF_2^-$ | HF |
|---|---|---|---|---|
| | Moles per 1000 grams of solvent | | | |
| 0.001 | 0.0006423 | 0.0006418 | 0.000000555 | 0.0003571 |
| .002 | .0010536 | .0010512 | .000002403 | .0009440 |
| .003 | .0013845 | .0013792 | .000005377 | .001610 |
| .005 | .0019263 | .0019121 | .00001417 | .003060 |
| .007 | .0023783 | .0023521 | .00002617 | .004596 |
| .01 | .0029603 | .0029111 | .00004927 | .006990 |
| .02 | .004494 | .004333 | .0001609 | .015345 |
| .05 | .007796 | .007084 | .0007117 | .04149 |
| .10 | .012040 | .009968 | .002073 | .08589 |
| .20 | .019284 | .013545 | .005739 | .17498 |
| .50 | .039426 | .019084 | .020342 | .44023 |
| 1.0 | .074271 | .023810 | .050461 | .87527 |
| 2.0 | .15358 | .029700 | .12388 | 1.7225 |
| 3.0 | .24705 | .034547 | .21250 | 2.5405 |
| 4.0 | .35623 | .039339 | .31689 | 3.3269 |

TABLE 8. *Relative ionic and molecular species in aqueous solutions of hydrofluoric acid at 25 °C*

(based on Debye-Hückel limiting law for activity coefficients)

| $m$ | $H^+$ | $F^-$ | $HF_2^-$ | HF |
|---|---|---|---|---|
| | Moles per 1000 grams of solvent | | | |
| 0.001 | 0.0005624 | 0.0005618 | 0.000000644 | 0.0004370 |
| .002 | .0008992 | .0008966 | .000002584 | .001098 |
| .003 | .0011667 | .0011612 | .000005570 | .001828 |
| .005 | .0016018 | .0015877 | .00001410 | .003384 |
| .007 | .0019633 | .0019378 | .00002549 | .005011 |
| .01 | .0024277 | .0023807 | .00004702 | .007525 |
| .02 | .0036494 | .0035005 | .0001489 | .01620 |
| .05 | .0062360 | .0056018 | .0006342 | .04313 |
| .10 | .0096962 | .0078689 | .0018273 | .08848 |
| .20 | .015561 | .010578 | .0049828 | .17946 |
| .50 | .032015 | .014667 | .017348 | .45064 |
| 1.0 | .060594 | .018066 | .042523 | .89688 |
| 2.0 | .12547 | .022210 | .10326 | 1.7713 |
| 3.0 | .20161 | .025576 | .17604 | 2.6224 |
| 4.0 | .29006 | .028856 | .26120 | 3.4487 |

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# Fluorine Flame Calorimetry III. The Heat of Formation of Chlorine Trifluoride at 298.15 K*

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The standard heat of formation of chlorine trifluoride (gas) at 298.15 K has been determined to be $-164.65$ kJ mol$^{-1}$ ($-39.35$ kcal mol$^{-1}$) with an overall experimental uncertainty of 5.14 kJ mol$^{-1}$ (1.23 kcal mol$^{-1}$). This value is derived from the enthalpies of the following reactions which were measured directly in a flame calorimeter operated at 1 atm pressure and 303.5 K, together with data from previous investigations.

$$ClF_3(g) + 2H_2(g) + 100H_2O(l) \rightarrow [HCl\cdot 3HF\cdot 100H_2O](l)$$

$$(1/2)Cl_2(g) + 1/2H_2(g) + [3HF\cdot 100H_2O](l) \rightarrow [HCl\cdot 3HF\cdot 100H_2O](l)$$

The enthalpy of formation of $[HCl\cdot 100H_2O](l)$ was also measured. The average Cl–F bond energy in chlorine trifluoride is calculated to be 160.1 kJ mol$^{-1}$ (38.26 kcal mol$^{-1}$).

Key words: Bond energy (Cl–F); chlorine reaction with hydrogen; chlorine trifluoride, heat of formation; flame calorimetry; flow calorimetry; fluorine compounds; heat of formation; heat of reaction; hydrogen chloride (aqueous), heat of formation; mixed acids: $(HCl + 3HF)_{aq}$, heat of formation; reaction calorimetry; reaction with hydrogen.

## 1. Introduction

Chlorine trifluoride is a vigorous fluorinating agent which combines spontaneously with many other compounds and elements. This fluorine-containing oxidizer is easily liquefied, and for this reason, has some applications different from those of other fluorine compounds. However, as with the other fluorine-containing oxidizers, the special applications of chlorine trifluoride, such as its use in rocket propulsion, require accurate thermochemical data.

In the past, there have been few original studies on the heat of formation of chlorine trifluoride. Possibly this is caused by its extreme reactivity, which is the greatest obstacle to a definitive study of its heat of formation. Schmitz and Schumacher [1][1] and Schäfer and Wicke [2] determined equilibrium constants at various temperatures for the reaction, $ClF_3(g) \rightarrow ClF(g) + F_2(g)$. Von Wartenberg and Riteris [3] and Schmitz and Schumacher [4] measured the heat of the reaction, $ClF_3(g) + 3NaCl(c) \rightarrow 3NaF(c) + 2Cl_2(g)$. These studies have been evaluated repeatedly in different reviews for the purpose of selecting a "best" value for $\Delta H_f(ClF_3)$. The values currently given are $-38.0$ [5] and $-38.869 \pm 1.0$ [6] kcal mol$^{-1}$. It is difficult to analyze the reasons for the relatively small uncertainties in these data and no further attempt will be made at this time. The principal reason for undertaking this work was that evidence from some test rocket propulsion studies, and some unpublished thermochemical information suggested that the enthalpy of formation might be in the range of $-26$ kcal mol$^{-1}$, a difference of over 10 kcal mol$^{-1}$ from the published values.

In the present study, the heat of formation of chlorine trifluoride is determined by fluorine flame calorimetry, a technique which is very different from techniques used in earlier studies on this substance. The advantages of this technique are discussed in detail in recent reports on the heat of formation of other fluorine compounds studied in this laboratory [7, 8]. The determination of the heat of formation of chlorine trifluoride by direct combination of the elements is complicated by the formation of mixed halides. As an alternative, the reaction of chlorine trifluoride with hydrogen followed by solution of the products to form an aqueous mixture of hydrofluoric and hydrochloric acids was selected for this study.

The heat of formation of chlorine trifluoride, the enthalpy of reaction (1), is derived from reactions (2), (3), (4), and (5). (Reaction 1 = Reaction (3 + 4 − 5 − 2).) The heats of the $ClF_3 - H_2 - H_2O$, and $Cl_2 - H_2 = HF(aq)$,

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[1] Figures in brackets indicate the literature references at the end of this paper.

reactions, (2) and (3), were measured directly in this study. The heat of the $F_2-H_2-H_2O$ reaction (4) was studied earlier [8], and a necessary dilution energy, the enthalpy of reaction (5), obtained from the literature [5].

The calorimeter was calibrated with the oxygen-hydrogen reaction (6).

$$1/2Cl_2(g)+3/2F_2(g)\rightarrow ClF_3(g) \quad (1)$$

$$ClF_3(g)+2H_2(g)+100H_2O(l)\rightarrow [HCl\cdot 3HF\cdot 100H_2O](l) \quad (2)$$

$$1/2Cl_2(g)+1/2H_2(g)+[3HF\cdot 100H_2O](l)\rightarrow [HCl\cdot 3HF\cdot 100H_2O](l) \quad (3)$$

$$3/2F_2(g)+3/2H_2(g)+150H_2O(l)\rightarrow [3HF\cdot 150H_2O](l) \quad (4)$$

$$[3HF\cdot 100H_2O](l)+50H_2O(l)\rightarrow [3HF\cdot 150H_2O](l) \quad (5)$$

$$1/2O_2(g)+H_2(g)\rightarrow H_2O(l) \quad (6)$$

$$1/2Cl_2(g)+1/2H_2(g)+100H_2O(l)\rightarrow [HCl\cdot 100H_2O](l) \quad (7)$$

Reaction (7) is closely related to reaction (3). Because accurate data for reaction (7) are available in the literature, a measurement of the enthalpy gives a way of checking the overall validity of the procedures used in this study.

## 2. Experimental Apparatus and Procedures

### 2.1. The Samples

Commercially available samples of hydrogen, oxygen, chlorine, and chlorine trifluoride were used. The oxygen and hydrogen samples were of high purity and are the same grades used for earlier flame calorimetric studies [8]. The mass fraction of $O_2$ in the oxygen sample was 0.99987 and the mole fraction of $H_2$ in the hydrogen sample was 0.999. The hydrogen was used directly from the source cylinder. Each of the oxidizer gases was used from small weighable containers with a volume of about 250 $cm^3$ [7, 8]. The containers were chilled with solid carbon dioxide to condense the chlorine and chlorine trifluoride into them.

*Chlorine*—The chlorine sample was a high purity grade and was not subjected to any additional purification. The chlorine was transferred to the weighable container and was contained as a liquid under its vapor pressure of 5.8 atm at 25 °C. The purity was checked using the mercury-absorption method [8, 9, 10], and subsequent analysis of the residual gas by mass spectrometry. In carrying out the usual procedure some of the sample from the weighable container was transferred to an evacuated Pyrex glass bulb containing mercury. The bulb was immersed in hot water to initiate the reaction. The composition of the chlorine as found by this analysis is given in table 1.

*Chlorine trifluoride*—The chlorine trifluoride was contained as a liquid under its vapor pressure of 1.47 atm at 25 °C. The principal impurities in the chlorine trifluoride sample were hydrogen fluoride, oxygen, nitrogen, and carbon dioxide. In the process of transfer to the weighable container the gas was passed over activated sodium fluoride for removal of the hydrogen fluoride.

TABLE 1. *Compositions of the chlorine and chlorine trifluoride samples*

| Constituent | Sample | |
|---|---|---|
| | $ClF_3$ (gas phase) | $Cl_2$ |
| | *Weight percent* | |
| $ClF_3$ | 99.82 | – |
| $Cl_2$ | – | 99.93 |
| $F_2$ | – | – |
| $O_2$ | 0.15 | 0.02 |
| $N_2$ | .01 | .05 |
| Ar | * | * |
| $CO_2$ | 0.01 | * |
| $CF_4$ | * | – |
| $C_2F_6$ | * | – |
| $C_3F_8$ | * | – |
| $C_4F_8$ | * | – |
| $SO_2F_2$ | – | – |
| $SiF_4$ | – | – |

– Not detected.
*Traces detected.

After removal of the hydrogen fluoride, the remaining impurities are more volatile than the chlorine trifluoride. It is possible that the sample becomes purer in chlorine trifluoride as a series of experiments is completed. To check this point, duplicate analyses were performed on the sample at different times. The results showed the sample to contain 0.47 and 0.45 mole percent impurities, and give no evidence of such a fractionation.

For a quantitative analysis of the sample, as with the chlorine, the chlorine trifluoride was reacted with mercury and the residual gas was analyzed by mass spectrometry. Chlorine trifluoride reacts vigorously with mercury. For these analyses the mercury and container were conditioned with chlorine trifluoride and then reevacuated prior to filling to the final pressure of 1 atm. The results of the analyses are given in table 1.

Limitations of the absorption method have been discussed [8]. Possible impurities that would also react with the mercury under the conditions of the test are $Cl_2$, ClF, and Cl–O–F compounds. Oxygen liberated by reactions of impurities might affect the observed amount of free oxygen. The possible errors due to lack of information about such impurities are taken into account in the discussion of errors.

### 2.2. The Reaction Vessel and Flow System

The reaction vessel is illustrated in figure 1. It consists of a heat exchanger, combustion chamber, two solution vessels, various connecting tubes; and smaller parts. See section 2.3 for a brief description of its use. It is similar to the one used for the study of oxygen difluoride which has already been described [8]. The

FIGURE 1. *Assembled reaction vessel.*

The principal change from the vessel previously described is the substitution of the secondary solution vessel in the foreground for a smaller one previously used.

main modification is the use of a secondary solution vessel of a volume equal to that of the primary solution vessel in place of a smaller secondary solution vessel. This change was made because of significant losses of the mixed acids when the smaller secondary vessel was used. The undersides of the Monel[2] lids to the solution vessels were coated with polytetrafluoroethylene (PTFE). For an experiment each solution vessel contained 100 $cm^3$ of water.

In addition to its greater volatility from the aqueous solutions the mixture of hydrogen chloride and hydrogen fluoride formed in the chlorine trifluoride-hydrogen reaction was observed to be extremely corrosive in the combustion chamber. To minimize loss of the acid by corrosion, a removable platinum liner (0.05 mm thick) was placed in the lower part of the combustion chamber. For the chlorine-hydrogen reactions, a platinum liner was also placed on the underside of the lid to the combustion chamber. Platinum in this position was found to be very unsuitable for the chlorine trifluoride experiments. In preliminary experiments with chlorine trifluoride, a liner on the lid vaporized to a certain extent, leaving a soot-like deposit on the walls of the combustion chamber. A spectrochemical analysis of this deposit revealed it to be platinum.

The overall design of the flow system is similar to that used earlier. The major modification was introduced in the oxidizer flow line. A commercially available mass flowmeter operating on a thermal conductivity principle was inserted in the oxidizer flow line. This modification is shown in figure 2. However, because of the extreme reactivity of chlorine trifluoride, the Pyrex flowmeter was replaced with a stand-in Monel tube for the chlorine trifluoride experiments. The Pyrex flowmeter was used satisfactorily for the oxygen and the chlorine reactions and was found very useful for monitoring the $O_2$—$H_2$ and $Cl_2-H_2$ flames.

### 2.3. The Calorimetric Procedures and Calculations

The calorimeter and its operation were the same as used in an earlier study [8]. The temperature of the jacket water was controlled at 32 °C. The reactions were initiated with a high voltage spark.

The experiments were conducted using procedures similar to those developed for the oxygen difluoride study. The oxidizer was introduced into a flowing atmosphere of excess hydrogen and reacted in a steady flame. The products of combustion passed into the aqueous phase in the primary solution vessel, immediately below, where most of the products were absorbed. The small amount that passed beyond the primary solution vessel was absorbed in the secondary solution vessel. The reaction periods ranged from approximately 10 to approximately 20 minutes.

Initially the low vapor pressure of chlorine trifluoride caused some difficulty in maintaining the $ClF_3-H_2$ flame. As the $ClF_3$ was released from the bulb, the cooling effect of the vaporization caused a lowering of the vapor pressure and as a result, the flame was sometimes extinguished. This problem was solved by immersing the sample bulb in a water bath at 30 °C.

The calculations of the temperature data were made with a FORTRAN computer program written by Shomate [11]. The quantities obtained from the program include $\Delta t_c$, $\Delta t$(corr), and $t$(av). See section 4 for definitions.

The heat capacity data used for the calculations are given in table 1a. For this paper the calorie is taken as 1 cal = 4.184 J. The atomic weights are taken from the 1961 table of Atomic Weights based on carbon 12 [12]. The heats of vaporization of water are 2439 and 2428 J $g^{-1}$ at 298.15 and 303.15 K, respectively [13].

TABLE 1a. *Heat capacity data*

| Substance | $C_p$ 298.15 J $mol^{-1}$ $K^{-1}$ | Reference |
|---|---|---|
| $ClF_3$(g) | 63.85 | [5] |
| $O_2$(g) | 29.36 | [5] |
| $Cl_2$(g) | 33.91 | [5] |
| $H_2$(g) | 28.82 | [5] |
| $H_2O$(l) | 75.291 | [5] |
| HCl(100$H_2O$)(l) | −116.3 | [16] |

[2] Certain commercial products are identified in this paper in order to specify adequately the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the products identified are necessarily the best for the purpose.

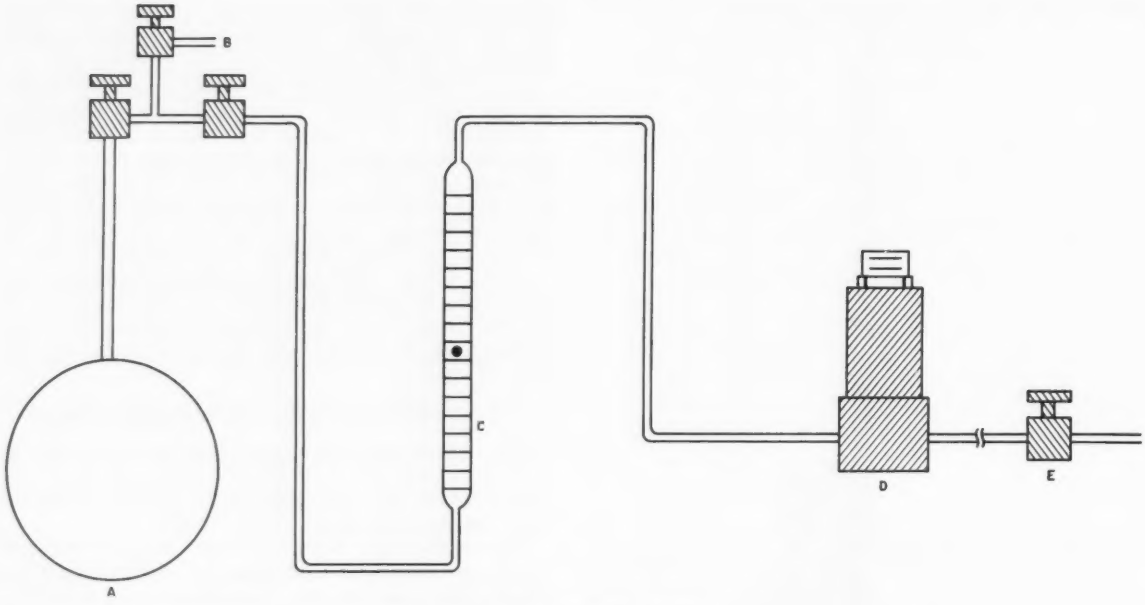


FIGURE 2. *The oxidizer flow line.*

A, Sample container; B, Helium source; C, Pyrex flowmeter; D, Mass-flowmeter transducer; E, Valve opening to the reaction vessel.

### 2.4. The Removal of Water from the Reaction Vessel

The continual flow of hydrogen through the reaction vessel causes a removal of water vapor from the inside to the outside of the calorimeter. To reduce errors in the corrected temperature rise the net water removal was minimized by adding a similar amount of water as vapor to the reaction vessel. To do this the hydrogen was passed through saturators placed just before the calorimeter [8]. The net thermal effect of evaporation is observed as a part of the temperature drift rate of the calorimeter in the initial and final periods. As a check on the magnitude of this effect the amounts of water carried into and removed from the reaction vessel were measured and are compared in table 2. Except for the $Cl_2-H_2-H_2O$ reaction, the compensation is fairly close, the net increase in the reaction vessel ranging from $-0.13$ to $+0.10$ g. There is a consistently larger increase in the water content of the reaction vessel for the $Cl_2-H_2-H_2O$ reaction, the net increase ranging from 0.27 to 0.60 g. The explanation for this larger increase is unknown, but may be due to a pronounced lowering of the vapor pressure of water by HCl alone in contrast to its behavior when mixed with HF. The corrected temperature rises are expected to be accurate, nevertheless, because the increase is presumed to occur over the 60–70 min experimental period and to be uniform during the drift periods. During the reaction period a certain fraction of the gases entering the calorimeter does not leave the calorimeter. The thermal effect of condensation of water from this amount of gas is applied as a correction (see $q$(vap), sec. 4.1).

TABLE 2. *Water changes in reaction vessel*

| Expt. No. | Water removed g | Water carried in g | Net increase g |
|---|---|---|---|
| Oxygen-hydrogen reaction | | | |
| 1 | 0.7634 | 0.8615 | 0.0981 |
| 2 | .8477 | .8574 | .0097 |
| 3 | 1.0371 | 1.0635 | .0264 |
| 4 | 1.0463 | 0.9446 | −.1017 |
| 5 | 0.7795 | .8828 | .1033 |
| 6 | .7060 | .7508 | .0448 |
| Chlorine trifluoride-hydrogen-water-reaction | | | |
| 1 | 0.5959 | 0.5781 | −0.0178 |
| 2 | .7055 | .7589 | .0534 |
| 3 | .5679 | .6636 | .0957 |
| 4 | .6038 | .6484 | .0446 |
| 5 | .7337 | .7408 | .0071 |
| 6 | .6998 | .7184 | .0186 |
| Chlorine-hydrogen-water reaction | | | |
| 1 | 0.3229 | 0.6809 | 0.3580 |
| 2 | .3016 | .5931 | .2915 |
| 3 | .5554 | .8235 | .2681 |
| 4 | .8892 | 1.4887 | .5995 |
| Chlorine-hydrogen-$HF_{aq}$ reaction | | | |
| 1 | 0.8163 | 0.7222 | −0.0941 |
| 2 | .9960 | .8689 | −.1271 |
| 3 | ..... | .8010 | ..... |
| 4 | .6777 | .6136 | −.0641 |
| 5 | .8135 | .7377 | −.0758 |

The analysis data for the $ClF_3-H_2$-$H_2O$ reaction are given in table 3. $n_{H^+}$(obs) and $n_{H^+}$(calc) are the observed and calculated amounts of acid respectively. The completeness of the reaction is shown by

$$\frac{n_{H^+}(\text{obs})}{n_{H^+}(\text{calc})}.$$

The generally low values of this ratio can be explained by the extremely reactive character of the acid mixture, $HCl \cdot 3HF$. No explanation is offered for the erratic but favorable value for experiment 5. It is immaterial whether the chlorine trifluoride sample reacts directly with the metal or whether it reacts with hydrogen to completion inside the reaction vessel and the corrosion results from the reaction of the product acid with the metal, the results will show up as a deficiency of total acidity of the solution. Therefore, $n_{ClF_3}$(corros) is derived from the difference between $n_{H^+}$(obs) and $n_{H^+}$(calc). This neglects the possibility that some HCl—HF or unreacted $ClF_3$ may have escaped from the reaction vessels.

The $\frac{n_{H^+}(\text{obs})}{n_{H^+}(\text{calc})}$ values shown here resemble those for the $F_2-H_2-H_2O$ reaction which were reported earlier [8]. After the $ClF_3-H_2-H_2O$ reaction, the combustion chamber of the reaction vessel does show a considerable amount of corrosion, especially on the burner tip. A yellowish-green discoloration appears on the walls. In comparison with the noble metals, Monel still appears to be the most suitable material for construction of reaction containers for chlorine trifluoride. Possibly the recovery of the acid in these experiments could be improved by using a larger reaction vessel and a large amount of excess hydrogen during the reaction.

TABLE 3. *Completeness of the* $ClF_3-H_2-H_2O$ *reaction*

| Expt. No. | 1 | 2[a] | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $m_s$.....g... | 5.5074 | 5.3577 | 5.1142 | 4.4999 | 5.2142 | 4.9769 |
| $n_{H^+}$(obs).....mol... | 0.23262 | 0.22461 | 0.21545 | 0.19024 | 0.22349 | 0.21035 |
| $n_{H^+}$(obs)[b].....mol... | .23786 | .23140 | .22088 | .19435 | .22520 | .21495 |
| $n_{H^+}$(calc-obs).....mol... | .00524 | .00679 | .00543 | .00411 | .00171 | .00460 |
| $n_{ClF_3}$(corros).....mol... | .001310 | .001698 | .001358 | .001028 | .000428 | .001150 |
| $n_{H^+}$(obs)/$n_{H^+}$(calc)..... | .9780 | .9707 | .9754 | .9789 | .9924 | .9786 |
| $n_{H_2O}/n_{HCl}$..... | 96 | 99 | 102 | 117 | 99 | 105 |
| $n_{H_2O}/n_{HF}$..... | 32 | 33 | 34 | 39 | 33 | 35 |
| $n_{Cl^-}$(obs).....mol... | ..... | ..... | ..... | ..... | 0.05579 | ..... |
| $n_{F^-}$(obs).....mol... | ..... | ..... | ..... | ..... | .16716 | ..... |

[a] Not used in the final results.
[b] The molecular weight of $ClF_3$ is 92.4482. The sample purity was 0.9982. The value of $n_{H^+}$(calc) is given by $m_s \times 4 \times 0.9982/92.4482$.

## 3. The Completeness of the Reactions

The reactive nature of the reactants and products in the systems studied makes it difficult to determine the amounts of the desired reactions taking place. Yet this aspect of the study is critically important to the accuracy of the heats of reaction.

Our usual procedure of comparing the measured amount of the oxidizer introduced with the measured amount of the acid formed was used. Any deviation from a mass balance determined in this way was assumed to be caused by the corrosion reaction of the oxidizer with the reaction vessel. A correction, $q$(corros), is applied to the observed heat effect for this amount of corrosion.

The amount of chlorine trifluoride sample introduced into the reaction was determined by weighing the sample bulb to 0.1 mg before and after each experiment. The amount of chlorine trifluoride introduced was calculated using the analysis of the sample given in table 1. All chlorine trifluoride introduced was assumed to have reacted and the amount was used to calculate the anticipated amount of $H^+$, which we call $n_{H^+}$(calc). The total amount of acid formed was determined in the Analytical Chemistry Division at the National Bureau of Standards. To verify the results for the $H^+$, analysis for the $Cl^-$ and $F^-$ was performed for experiment 5. The sum of these is 0.2 percent less than the total hydrogen ion observed. In the absence of any obvious source of this difference it may be taken as due to a small systematic difference between the methods of analysis. The amounts of $H^+$ and $Cl^-$ were measured using two independent coulometric methods. The $F^-$ determination was performed by potentiometric titration with standard $LaCl_3$ solution, using a fluoride-activity-indicator electrode.

From the data shown in table 3, a value of 0.3337 is derived for $\frac{n_{Cl^-}}{n_{F^-}}$, which is not significantly different from the theoretical ratio of 0.3333. This suggests that any undetected impurities in the chlorine trifluoride sample are present in very small amounts or have the same Cl:F ratio.

The analysis data for the $Cl_2-H_2-H_2O$ and $Cl_2-H_2-HF_{aq}$ reactions are given in table 4. The $n_{H^+}$(obs) excluding the $H^+$ introduced as $HF_{aq}$ is shown as $n_{HCl}$(obs) for each experiment. The value of $n_{Cl^-}$(obs) is given for a typical experiment. Compared

TABLE 4. *Completeness of the* $Cl_2-H_2-H_2O$ *and* $Cl_2-H_2-HF_{aq}$ *reactions*

| Expt. No. | $Cl_2-H_2-H_2O$ | | | | $Cl_2-H_2-HF_{aq}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 5 | 6 |
| $m_s$ ..... g... | 9.6607 | 6.7661 | 6.6417 | 7.6865 | 2.1408 | 2.5748 | 4.4517 | 2.2925 | 1.5869 |
| $n_{HCl}$(obs) ..... mol... | 0.26976 | 0.19053 | 0.18702 | 0.21625 | 0.06019 | 0.07250 | 0.12526 | 0.06416 | 0.04457 |
| $n_{HCl}$(calc) ..... mol... | .27230 | .19070 | .18720 | .21664 | .06034 | .07258 | .12548 | .06466 | .04444 |
| $\Delta n_{HCl}$(calc-obs) ..... mol... | .00254 | .00017 | .00018 | .00039 | .00015 | .00008 | .00022 | .00050 | −.00013 |
| $n_{Cl_2}$(corros) ..... mol... | .001270 | .000085 | .000090 | .000195 | .000075 | .000040 | .000110 | .000250 | ..... |
| $n_{HCl}$(obs)/$n_{HCl}$(calc) | .9907 | .9990 | .9990 | .9982 | .9975 | .9989 | .9982 | .9923 | 1.0029 |
| $n_{H_2O}/n_{HCl}$ | 20 | 29 | 30 | 26 | 90 | 74 | 43 | 87 | 121 |
| $n_{H_2O}/n_{HF}$ | ..... | ..... | ..... | ..... | 33 | 32 | 32 | 32 | 32 |
| $n_{Cl^-}$(obs) ..... mol... | ..... | ..... | 0.18715 | ..... | ..... | ..... | ..... | ..... | ..... |
| $n_{H^+}$(obs) ..... mol... | ..... | ..... | .18702 | ..... | ..... | ..... | ..... | ..... | ..... |

to the $ClF_3-H_2-H_2O$ reactions, the recovery of the acid is improved considerably for the chlorine-hydrogen systems. This improved recovery of the acid probably is accounted for by the observations that (1) HCl alone is less reactive towards Monel than the HCl−3HF mixture and (2) lining the combustion chamber with platinum foil shields the monel from the HCl.

The $\frac{n_{Cl^-}(obs)}{n_{H^+}}$ value is 1.0007, slightly higher than the expected value of 1.0000. This trend was observed also for some preliminary experiments, and if real may indicate that some loss in acid is due to corrosion in which $H^+$ reacted.

Values of $n_{H_2O}/n_{HCl}$ and $n_{H_2O}/n_{HF}$ are shown in tables 3 and 4 and are used later to apply a heat-of-dilution correction to the final heats of reaction. The $HF_{aq}$ solutions were prepared and analyzed before the experiments. The desired amount was weighed into the solution vessel before assembly of the reaction vessel. Therefore, no subsequent analysis for the HF was required.

The amount of the $O_2-H_2$ reaction is based on the mass of oxygen reacted. For calibration purposes Rossini [14] recommends that the amount of reaction be based on the amount of water formed. In our earlier study, we measured the amount of water formed in a dry reaction vessel and compared this with the amount of oxygen reacted. The observed versus the expected amounts of water were in close agreement in that test. It is desirable to perform the "reaction" calibration using the same procedures used for the reaction involving the fluorine oxidizer. Because water is contained in the solution vessels, it is not convenient to collect the water formed in the $O_2-H_2$ reactions. Under these circumstances, we believe that the best accuracy is obtained by basing the amount of reaction on the amount of oxygen introduced into the reaction.

## 4. The Heat Measurements

### 4.1. The Calibration of the Calorimeter

#### The $O_2-H_2$ Reaction

The calorimeter was calibrated with the oxygen-hydrogen reaction using most of Rossini's recommended procedures [14]. The data for these experiments are given in table 5. The amount of oxygen is $n_{O_2}$ and is calculated from the mass of the sample, $m_s$, and its composition. The reference temperature for the reaction is $t$(av) and is the midtemperature between the initial and final temperatures of the reaction. The quantities $\Delta t$(corr) and $\Delta t_c$ are the correction to the temperature rise and the corrected temperature rise respectively. The quantity $q$(reaction) is the energy produced by reaction of $n_{O_2}$ moles of oxygen at $t$(av). To calculate $q$(reaction) from $n_{O_2}$ the value 571.28 kJ $mol^{-1}$ was used for the heat of reaction of oxygen with hydrogen to form liquid water at 304 K [5, 14].

The heat of ignition is $q$(ign) and was based on the rate of ignition-energy generation measured earlier [8]. Other corrections are: $q$(temp), the amount of heat required to raise the temperature of the reacting gases from room temperature to $t$(av); $q'$(vap), the heat of condensation of the water vapor carried by the hydrogen which is consumed by the reaction; $q''$(vap), the heat of vaporation of water by the helium which is introduced to transfer the oxidizer completely into the reaction vessel. The sum of the corrections (total), is applied to $q$(reaction) to obtain $q$(obs). The observed energy equivalent, $E$(obs), is the ratio of $q$(obs) to $\Delta t_c$. A small correction for the amount of water formed at $t$(ave), $\Delta e$, is added to the $E$(obs) to yield the energy equivalent of the standard calorimeter, $E$(calorim).

The standard calorimeter for the calibration and combustion experiments consisted of the calorimeter can with stirrer and lid, the calorimeter heater, the reaction vessel with 100 $cm^3$ of water in each solution vessel, a small neoprene plug used to close the opening around the outlet tube of the reaction vessel, the immersed portion of the thermometer, and a PTFE ring for sealing the thermometer opening. The average $E$(calorim) is 21949.1 J $K^{-1}$ with a standard deviation of the mean of 4.4 J $K^{-1}$.

The 0.02 percent standard deviation of the mean is larger than usually observed for calibrations in this laboratory. A more precise calibration may possibly be obtained when the amount of reaction is based on the amount of water formed, because any unreacted oxygen would then be accounted for.

TABLE 5. *The calibration of the calorimeter*

$H_2(g) + 1/2O_2(g) \rightarrow H_2O(l)$

| Expt. No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| a. Heat and reactant measurements | | | | | | |
| $m_s$.....g... | 2.8449 | 2.7814 | 2.8186 | 2.8405 | 2.8259 | 2.7795 |
| $n_{O_2}$.....mol... | 0.088895 | 0.086911 | 0.088073 | 0.088757 | 0.088301 | 0.086851 |
| $t$(av).....°C... | 30.42 | 30.42 | 30.41 | 30.41 | 30.41 | 30.43 |
| $\Delta t$(corr).....°C... | 0.07265 | 0.05807 | 0.06472 | 0.06297 | 0.06721 | 0.05849 |
| $\Delta t_c$.....°C... | 2.32293 | 2.26971 | 2.30022 | 2.31573 | 2.30197 | 2.26562 |
| $q$(reaction).....J... | 50783.9 | 49650.5 | 50314.3 | 50705.1 | 50444.6 | 49616.2 |
| b. Corrections to the heat data | | | | | | |
| $q$(ign).....J... | 24.9 | 36.7 | 22.7 | 22.7 | 24.5 | 26.7 |
| $q$(temp).....J... | −18.7 | −30.3 | −23.0 | −30.8 | −40.7 | −38.0 |
| $q'$(vap).....J... | 253.3 | 228.3 | 242.1 | 233.0 | 218.9 | 215.1 |
| $q''$(vap).....J... | −50.1 | −91.6 | −47.4 | −88.2 | −69.4 | −69.2 |
| Corrections (total).....J... | 209.4 | 143.1 | 194.4 | 136.7 | 133.3 | 134.6 |
| c. Energy equivalent of the calorimeter | | | | | | |
| $q$(obs).....J... | 50993.3 | 49793.6 | 50508.1 | 50841.8 | 50577.9 | 49750.8 |
| $E$(obs).....J(°C)$^{-1}$... | 21952.1 | 21938.3 | 21958.2 | 21955.0 | 21971.6 | 21959.0 |
| $\Delta e$.....J(°C)$^{-1}$... | 6.7 | 6.5 | 6.6 | 6.7 | 6.7 | 6.5 |
| $E$(calorim).....J(°C)$^{-1}$... | 21945.4 | 21931.8 | 21951.6 | 21948.3 | 21964.9 | 21952.5 |

### 4.2. The $ClF_3 - H_2 - H_2O$ Reaction

The heat data for the $ClF_3 - H_2 - H_2O$ reaction are given in table 6. Most of the symbols have been explained for the $O_2 - H_2$ reaction. Here $\Delta e$ is the increase in the energy equivalent caused by the addition of the product acids to the standard calorimeter. $E$(calorim) of table 5, corrected by $\Delta e$, yields $E(ClF_3)$. The heat of reaction of the oxygen impurity in the $ClF_3$ is $q_{O_2}$. The loss of acid due to corrosion of the reaction vessel is corrected by $q$(corros). In calculating $q$(corros) it is assumed that the product acids principally react with the Monel to yield nickel (II) chloride and nickel (II) fluoride. Then the overall corrosion reaction becomes:

$$ClF_3(g) + 2Ni(c) \rightarrow 1/2NiCl_2(c) + 3/2NiF_2(c)$$

for which $\Delta H$ was taken as $-964.8$ kJ(mol $ClF_3$)$^{-1}$ based on literature values [5] for the heats of formation of $NiCl_2$ and $NiF_2$ and preliminary results of these experiments for $ClF_3$.

TABLE 6. *The* $ClF_3 - H_2 - H_2O$ *reaction*

| Expt. No. | 1 | 2[a] | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| a. Heat measurements | | | | | | |
| $m_s$.....g... | 5.5074 | 5.3577 | 5.1142 | 4.4999 | 5.2142 | 4.9769 |
| $n_{ClF_3}$(calc).....mol... | 0.0594656 | 0.0578492 | 0.0552201 | 0.0485872 | 0.0562998 | 0.0537376 |
| $\Delta t$(corr).....°C... | .05725 | .06031 | .05414 | .05426 | .05437 | .05955 |
| $\Delta t_c$.....°C... | 2.61907 | 2.53343 | 2.42975 | 2.14235 | 2.48202 | 2.36713 |
| $t$(av).....°C... | 30.64 | 30.67 | 30.73 | 30.88 | 30.69 | 30.76 |
| $\Delta e$.....J(°C)$^{-1}$... | 3.4 | 3.3 | 3.1 | 2.8 | 3.2 | 3.1 |
| $E(ClF_3)$.....J(°C)$^{-1}$... | 21952.5 | 21952.4 | 21952.2 | 21951.9 | 21952.3 | 21952.2 |
| $q$(obs).....J... | 57495.1 | 55614.9 | 53338.4 | 47028.7 | 54486.0 | 51963.7 |
| b. Corrections to the heat measurements | | | | | | |
| $q$(ign).....J... | 56.0 | 41.4 | 36.3 | 38.4 | 33.3 | 42.8 |
| $q$(temp).....J... | −38.3 | −40.1 | −34.9 | −33.7 | −35.6 | −34.6 |
| $q'$(vap).....J... | 147.1 | 143.0 | 141.1 | 124.4 | 144.2 | 137.4 |
| $q''$(vap).....J... | −80.2 | −129.2 | −96.5 | −99.1 | −169.5 | −146.4 |
| $q_{O_2}$.....J... | 148.5 | 142.2 | 137.1 | 120.0 | 137.1 | 131.4 |
| Corrections (total).....J... | 233.1 | 157.3 | 183.1 | 150.0 | 109.5 | 130.6 |
| $q$(corros).....J... | 1263.9 | 1638.2 | 1310.2 | 991.8 | 412.9 | 1109.5 |
| $q_{ClF_3}(1)$.....J... | 57262.0 | 55457.6 | 53155.3 | 46878.7 | 54376.5 | 51833.1 |
| $q_{ClF_3}(2)$.....J... | 55998.1 | 53819.4 | 51845.1 | 45886.9 | 53963.6 | 50723.6 |
| $-\Delta H_{dil_n}$.....kJ(mol)$^{-1}$... | 0.07 | 0.01 | −0.02 | −0.14 | 0.01 | −0.05 |

[a] Not used in the final results.

Correction (total) is the sum of the corrections excluding $q$(corros). The heat of reaction of the chlorine trifluoride is $q_{ClF_3}(1)$, and is $q$(obs) minus corrections (total). The quantity $q_{ClF_3}(2)$ is equal to $q_{ClF_3}(1)$ minus the correction for corrosion, $q$(corros). The final item of the table, $-\Delta H_{diln}$ is the energy correction for the adjustment of the acid-water ratios (table 3) to $[HCl \cdot 100H_2O](l)$ and $[3HF \cdot 100H_2O](l)$. Note that this is a molar energy and is applied after conversion of the energy quantities to a molar basis.

The data for the enthalpy of reaction of chlorine trifluoride are tabulated in table 7. The reaction to which $\Delta H(1)$, $\Delta H(2)$, and $\Delta H(3)$ apply is shown at the beginning of the table. The heats of reaction are:

TABLE 7. *The enthalpy change of the* $ClF_3-H_2-H_2O$ *reaction.* 303.5 K

$$ClF_3(g)+2H_2(g)+100H_2O(l)\rightarrow[HCl\cdot 3HF\cdot 100H_2O](l)$$

| Expt. No. | $-\Delta H(1)^b$ kJ(mol $ClF_3)^{-1}$ (mass) | $-\Delta H(2)^b$ kJ(mol $ClF_3)^{-1}$ (titration) | $-\Delta H(3)^c$ kJ(mol $ClF_3)^{-1}$ (titration) |
|---|---|---|---|
| 1 | 963.01 | 984.71 | 962.98 |
| 2 | [a] 958.67 | [a] 987.64 | [a] 958.47 |
| 3 | 962.59 | 986.86 | 962.53 |
| 4 | 964.70 | 985.53 | 964.68 |
| 5 | 965.86 | 973.24 | 965.85 |
| 6 | 964.51 | 985.61 | 964.52 |
| Average | [d] 964.13 | 983.19 | [d] 964.11 |
| Standard deviation of the mean | 0.59 | 2.49 | 0.60 |

[a] Not included in the average.
[b] No correction for corrosion has been applied.
[c] Correction for corrosion has been applied.
[d] The close agreement of the average values of $\Delta H(1)$ and $\Delta H(3)$ is fortuitous and is due to the fact that the enthalpy change of the assumed corrosion reaction (Sec. 4.2) is extremely close to the enthalpy change of the reaction under study.

$\Delta H(1) = q_{ClF_3}(1)/n_{ClF_3}$ (mass) $- \Delta H_{diln}$; $\Delta H(2) = q_{ClF_3}(1)/n_{ClF_3}$ (titration) $-\Delta H_{diln}$; and $\Delta H(3)=q_{ClF_3}(2)/n_{ClF_3}$ (titration) $-\Delta H_{diln} \cdot \Delta H(1)$ is the heat of reaction of chlorine trifluoride introduced into the reaction, assuming no loss of the product acid due to corrosion. In calculating $\Delta H(2)$, we have imagined no corrosion, but used the product acid recovered as the basis of the amount of reaction. $\Delta H(3)$ is corrected for corrosion and is based on the observed amount of product acid. These three are the modes of calculation for which some justification could be presented.

In an earlier study on the heat of formation of oxygen difluoride, we made similar comparisons of the heat of reaction computed by these three methods of treating the heat data. From that study and also from the earlier discussion on the completeness of this reaction, there are clear indications that $\Delta H(3)$ is the most valid treatment of the data. Therefore, we take the heat of this reaction to be 964.11 (with a standard deviation of the mean of 0.60 kJ(mol $ClF_3)^{-1}$).

### 4.3. The Enthalpy Changes of the $Cl_2-H_2-H_2O$ and $Cl_2-H_2-HF_{aq}$ Reactions

The heat data for the $Cl_2-H_2-H_2O$ and $Cl_2-H_2-HF_{aq}$ reactions are given in tables 8 and 9. The symbols have the same meaning and the calculations were treated in the same way as those for the $ClF_3-H_2-H_2O$ reaction. The term $\Delta e$ is the correction to the energy equivalent for the HCl formed and $q_{O_2}$ corrects for the heat of reaction of the oxygen impurity. The quantity $q$(corros) is the heat of the reaction of chlorine with nickel and is based on the following reaction:

$$Cl_2(g)+Ni(c)\rightarrow NiCl_2(c)$$

$$\Delta H=-305.33 \text{ kJ(mol } Cl_2)^{-1}[5]$$

TABLE 8. *The* $Cl_2-H_2-H_2O$ *and* $Cl_2-H_2$-$HF_{aq}$ *reactions.*

303.5 K

| | $Cl_2-H_2-H_2O(l)$ | | | | $Cl_2-H_2-HF_{aq}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|
| a. Heat measurements | | | | | | | | | |
| Expt. No. | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 |
| $m_s$, g | 9.6607 | 6.7661 | 6.6417 | 7.6865 | 2.1408 | 2.5748 | 4.4517 | 2.2925 | 1.5869 |
| $\Delta t$(corr), °C | 0.10842 | 0.09534 | 0.08107 | 0.04724 | 0.02462 | 0.02384 | 0.03123 | 0.03243 | 0.02717 |
| $\Delta t_c$, °C | 2.04072 | 1.43670 | 1.41563 | 1.63739 | 0.45570 | 0.54595 | 0.95003 | 0.48592 | 0.33382 |
| $t$(ave), °C | 30.69 | 30.45 | 30.49 | 30.92 | 31.33 | 31.39 | 31.21 | 31.17 | 31.33 |
| $\Delta e$, J(°C)$^{-1}$ | 3.9 | 2.7 | 2.7 | 3.1 | −1.9 | −7.9 | −7.1 | −7.7 | −7.9 |
| $E(Cl_2)$, J(°C)$^{-1}$ | 21953.0 | 21951.8 | 21951.8 | 21952.2 | 21947.2 | 21941.2 | 21942.0 | 21941.4 | 21941.2 |
| $q$(obs), J | 44799.9 | 31538.2 | 31075.6 | 35944.3 | 10001.3 | 11978.8 | 20845.6 | 10661.8 | 7324.4 |
| b. Corrections to the heat measurements | | | | | | | | | |
| $q$(ign), J | 25.3 | 49.0 | 36.5 | 28.4 | 28.4 | 17.8 | 21.4 | 28.0 | 15.1 |
| $q'$(vap), J | 173.8 | 122.2 | 123.1 | 132.4 | 37.1 | 48.0 | 77.3 | 41.0 | 27.4 |
| $q''$(vap), J | −104.8 | −100.1 | −125.3 | −76.9 | −88.3 | −113.5 | −127.1 | −100.8 | −94.7 |
| $q$(temp), J | −46.9 | −31.3 | −26.4 | −40.2 | −12.1 | −14.2 | −23.8 | −12.1 | −8.8 |
| $q_{O_2}$, J | 28.6 | 22.9 | 22.9 | 22.9 | 5.7 | 11.4 | 11.4 | 5.7 | 5.7 |
| Corrections (total), J | 76.0 | 62.7 | 30.8 | 66.6 | −29.2 | −50.5 | −40.8 | −38.2 | −55.3 |
| $q$(corros), J | 387.8 | 26.0 | 27.5 | 59.5 | 22.9 | 12.2 | 33.6 | 76.3 | ..... |
| $q_{Cl_2}(1)$, J | 44723.9 | 31475.5 | 31044.8 | 35877.7 | 10030.5 | 12029.3 | 20886.4 | 10700.0 | 7379.7 |
| $q_{Cl_2}(2)$, J | 44336.1 | 31449.5 | 31017.3 | 35818.2 | 10007.6 | 12017.1 | 20852.8 | 10623.7 | 7379.7 |
| $-\Delta H_{diln}$, kJ(mol)$^{-1}$ | 2.08 | 1.26 | 1.26 | 1.76 | 0.12 | 0.21 | 0.79 | 0.08 | −0.08 |

TABLE 9. *The enthalpy changes of the* $Cl_2-H_2-H_2O$ *and* $Cl_2-H_2-HF_{aq}$ *reactions*

303.5 K

I. $1/2Cl_2(g) + 1/2H_2(g) + 100H_2O(l) \rightarrow [HCl:100H_2O](l)$
II. $1/2Cl_2(g) + 1/2H_2(g) + [3HF:100H_2O](l) = [HCl \cdot 3HF \cdot 100H_2O](l)$

| | $-\Delta H(1)$ [a] | $-\Delta H(2)$ [a] | $-\Delta H(3)$ [b] |
|---|---|---|---|
| Expt. No. | kJ(mol $HCl_{aq}$)$^{-1}$ | | |
| **I** | | | |
| 1 | 166.32 | 167.87 | 166.43 |
| 2 | 166.31 | 166.46 | 166.32 |
| 3 | 167.10 | 167.26 | 167.11 |
| 4 | 167.37 | 167.67 | 167.39 |
| Average | 166.78 | 167.32 | 166.81 |
| Standard deviation of the mean | 0.27 | 0.32 | 0.27 |
| **II** | | | |
| 1 | 166.35 | 166.77 | 166.39 |
| 2 | 165.95 | 166.13 | 165.96 |
| 3 | 167.24 | 167.53 | 167.27 |
| 4 | 165.56 | 166.85 | 165.66 |
| 5 | 165.98 | 165.50 | 165.50 |
| Average | 166.22 | 166.56 | 166.16 |
| Standard deviation of the mean | 0.32 | 0.34 | 0.31 |

[a] No correction for corrosion has been applied.
[b] Correction for corrosion has been applied.

## 5. Derivation of $\Delta H_f[ClF_3]$

### 5.1. Discussion of Errors in the $ClF_3-H_2-H_2O$, $Cl_2-H_2-H_2O$, and $Cl_2-H_2-HF_{aq}$ Reactions

The total uncertainty in the heats of reaction is calculated by combining the random errors with the total systematic errors. The error analysis is summarized in table 10. For each system the total random error is obtained by combining the standard deviations of the means for the calibrations ($\sigma_c$) and reaction ($\sigma_r$). We shall refer to this error ($2\sqrt{\sigma_r^2+\sigma_c^2}$) as the imprecision [18].

The systematic error in the calibration is independent of the remaining systematic chemical errors and depends on the accuracy of the $O_2-H_2$ reaction [15]. The systematic error in the $ClF_3$ measurements caused by uncertainty in the analysis of the sample is estimated to be 0.2 percent. This estimate takes into the account the possible presence of $Cl-O-F$ compounds in the sample which could not be analyzed for by the methods available. An analysis of the enthalpy of reaction versus the percent correction for corrosion for the $ClF_3-H_2-H_2O$ experiments suggests a certain amount of irrelevance or lack of appropriateness in the correction for corrosion. A plot of $\Delta H(2)$ and $\Delta H(3)$ versus percent correction for corrosion (100 $q$(corros)/$q_{ClF_3}(2)$) is given in figure 3 (Lines I and II, respectively). The intercepts are the enthalpies of reaction if there is no corrosion and the intercepts agree closely for the two curves. However, the slope for curve II representing the heats of reaction corrected for corrosion, is larger than expected. This causes a comparatively large difference between the intercept 967.30 and the average $-\Delta H(3)$, 964.11 kJ (mol $ClF_3^{-1}$) given in table 7. The difference in these values conceivably could be caused by an error in the data for one of the experiments (experiment 5). In plotting the data, an error in this point could cause a sizable slope of the line. A modest error can cause a large deviation in the intercept. The residual slope is the reason for assuming the $q$(corros) to be somewhat irrelevant and assigning the 0.33 percent systematic error for irrelevance of the corrosion correction. The average value rather than the intercept is adopted as the valid value for $\Delta H(3)$. The slope of the adjusted data, when compared with similar data for $OF_2$ and $F_2$[8], can also be interpreted as a more pronounced effect than had previously been observed, but in the same direction. If taken rigorously it is apparently the result of an over-correction for the corrosion. This could occur, for instance, if the energy of the corrosion reaction is assigned too great a value, or if the difference in $n_{ClF_3}$ (mass) and $n_{ClF_3}$ (titration) is exaggerated by loss of material from the calorimeter. While we consider these to be real possibilities, we consider their application to the data to be too speculative to present here.

TABLE 10. *Summary of errors*

| $\Delta H_{R\ 303\ K}$, kJ mol$^{-1}$ | 964.11 ± 4.99 | | 166.81 ± 0.57 | | 166.16 ± 0.57 | |
|---|---|---|---|---|---|---|
| | $ClF_3-H_2-H_2O$ | | $Cl_2-H_2-H_2O$ | | $Cl_2-H_2-HF_{aq}$ | |
| | % | kJ mol$^{-1}$ | % | kJ mol$^{-1}$ | % | kJ mol$^{-1}$ |
| Random Errors | | | | | | |
| Calibration ($\sigma_c$) | 0.02 | 0.19 | 0.02 | 0.03 | 0.02 | 0.03 |
| Reaction measurement ($\sigma_r$) | .062 | .60 | .16 | .27 | .17 | .28 |
| Imprecision $2\sqrt{\sigma_r^2+\sigma_c^2}$ | .131 | 1.26 | .32 | .53 | .32 | .53 |
| Systematic Errors | | | | | | |
| Calibration [15] | .014 | .13 | .01 | .02 | .01 | .02 |
| Analysis | .20 | 1.93 | .02 | .03 | .02 | .03 |
| Corrosion (irrelevance) | .33 | 3.19 | | | | |
| Total Chemical Error | .39 | 3.73 | .02 | .03 | .02 | .03 |
| Overall Systematic Error | .39 | 3.73 | .022 | .04 | .022 | .04 |
| Uncertainty | .52 | 4.99 | .34 | .57 | .34 | .57 |
| Uncertainty (kcal mol$^{-1}$) | | 1.19 | | .14 | | .14 |

A statistical analysis of curves I and II leads to the 95 percent confidence limits for intercept and slope shown in figure 3. At the 95 percent confidence limit the slope of curve II does not differ from zero, and this is consistent with our selection of the mean value as the best value of $\Delta H(3)$. The mean value is also within the 95 percent confidence limits of the intercept. The possible systematic error due to the corrosion correction is taken to be the difference between the mean value and the intercept, 3.19 kJ $mol^{-1}$.

The chemical errors are the analysis and corrosion errors. They are independent and are therefore combined as the square root of the sum of the squares of the individual errors. The overall systematic error is added to the imprecision to obtain the total uncertainty.

### 5.2. The Heat of Formation of $ClF_3$ at 298.15 K

The heat of formation of chlorine trifluoride is based on the reactions and heat data given in table 11. The heats of reactions (2) and (3) were presented in tables 7 and 9 and the uncertainties were derived above. The enthalpy of reaction (4) was taken from [8], and of reaction (5) from [5].

The heat of formation of $ClF_3$ becomes $164.65 \pm 5.14$ kJ $mol^{-1}$ at 303.5 K. This value remains unchanged when adjusted to 298.15 K. The estimated uncertainty is the square root of the sum of the squares of the errors for the heats of the reactions including twice the standard deviation of the mean of the experiments.

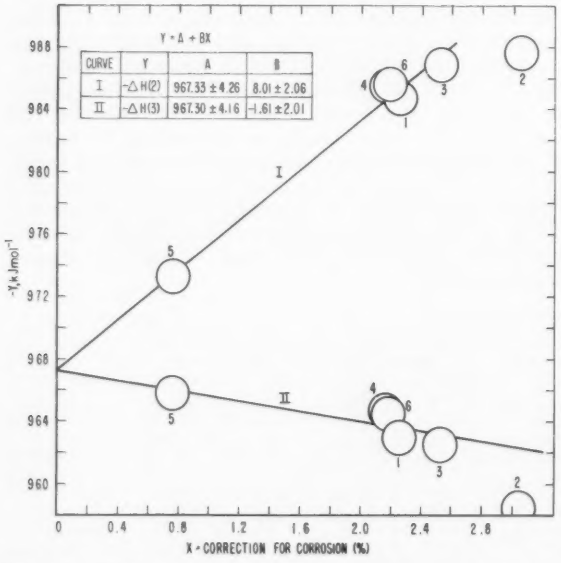


FIGURE 3. *Variation of the molar enthalpy of reaction for the* $ClF_3 - H_2 - H_2O$ *reaction with correction for corrosion.*

Values of Y, $-\Delta H(2)$ and $-\Delta H(3)$, are taken from table 7. Values of X are $100 \times q(\text{corros})/q_{ClF_3}(2)$, from table 6.

Lines I and II were derived by least squares analysis of the data. Data points are identified by the experiment number. Data point 2 was not used in the derivation of the equations. Constants for the equations are given in the box. Uncertainties listed are 95 percent confidence limits based on 5 data points and 3 degrees of freedom.

TABLE 11. *The heat of formation of* $ClF_3(g)$

303.5 K

| | $\Delta H$ and Total Uncertainty[a] kJ $mol^{-1}$ | |
|---|---|---|
| $ClF_3(g) + 2H_2(g) + 100H_2O(l)$ $\rightarrow [HCl \cdot 3HF \cdot 100H_2O](l)$ | $-964.11 \pm 4.99$ | (2) |
| $1/2Cl_2(g) + 1/2H_2(g) + [3HF \cdot 100H_2O](l)$ $\rightarrow [HCl \cdot 3HF \cdot 100H_2O](l)$ | $-166.16 \pm 0.57$ | (3) |
| $3/2F_2(g) + 3/2H_2(g) + [150H_2O](l)$ $\rightarrow [3HF \cdot 150H_2O](l)$ | $-962.64 \pm 1.0$ | (4) |
| $[3HF \cdot 100H_2O](l) + 50H_2O$ $\rightarrow [3HF \cdot 150H_2O](l)$ | $-0.04$ | (5) |
| $1/2Cl_2(g) + 3/2F_2(g) \rightarrow ClF_3(g)$[Note] | $-164.65 \pm .14$ ($-39.35 \pm 1.23$ kcal $mol^{-1}$) | (1) |

[Note] Reaction 1 is the sum of Reaction $(3+4-5-2)$.
[a]Estimated 95 percent confidence limits.

It, therefore, indicates approximately the 95 percent confidence limits of the value.

### 5.3. The Mixed Acid Solutions, $HCl \cdot 100H_2O$ and $HCl \cdot 3HF \cdot 100H_2O$

It is interesting to compare the difference between the heats of reaction of $Cl_2$ and $H_2$ to form $[HCl \cdot 100H_2O]$ and $[HCl \cdot 3HF \cdot 100H_2O]$. The values are $166.81 \pm 0.57$ kJ (mol HCl)$^{-1}$ and $166.16 \pm 0.57$ kJ (mol HCl)$^{-1}$. When the uncertainties are applied, the two values overlap. This indicates that the HF present has little thermal effect on the solution of HCl for a 1:3 ratio of HCl to HF.

### 5.4. The Heat of Formation of $[HCl \cdot 100H_2O](l)$ at 298.15 K

A definitive study of the heat of formation of [HCl: $100H_2O$] was not the main purpose of this study. However, it is of interest to compare the results with the selected data in the literature as an indication of the overall validity of the methods used. For $[HCl \cdot 100H_2O]$, a value of $-165.92$ kJ $mol^{-1}$ (39.657 kcal $mol^{-1}$) is reported [5]. This value is based on the earlier study on the $Cl_2 - H_2$ system performed by Rossini [15], and the enthalpy of solution data given by Parker [16]. A value of $-166.81 \pm 0.57$ kJ $mol^{-1}$ at 303.5 K is obtained here (Reaction 7). By our reduction to 298.15 using heat capacity data for $H_2$ and $Cl_2$ from [5] and for $HCl \cdot 100H_2O$ from [16] we calculate $\Delta H^\circ_{298.15} = -166.02$ kJ $mol^{-1} \pm 0.57$ kJ $mol^{-1}$. The difference from the selected value is well within the uncertainty assigned to the measurements. An important difference between our study and Rossini's is our use of a metal reaction vessel, compared to the Pyrex burner in Rossini's investigation. Also, our study leads directly to the formation of $[HCl \cdot 100H_2O]$ from $Cl_2$, $H_2$, and liquid water.

### 5.5. The Cl—F Bond Energy

The average Cl—F bond energy in $ClF_3$ is derived to be 38.25 kcal $mol^{-1}$, on the basis of the enthalpy of for-

mation of chlorine trifluoride presented in this paper, $\Delta H_f^\circ[Cl(g)] = 29.082$ kcal mol$^{-1}$ [5] and the recent energy of dissociation of fluorine, $\Delta H_f^\circ[2F(g)] = 30.9$ kcal mol$^{-1}$, reported by Dibeler, Walker, and McCulloh [17].

$$1/3ClF_3(g) \rightarrow 1/3Cl + F$$

$$\frac{-39.35}{3} \qquad \frac{29.082}{3} \qquad 15.45$$

$$E(Cl-F) = 38.26 \text{ kcal mol}^{-1} \text{ (160.1 kJ mol}^{-1}\text{)}$$

In a later report on the enthalpy of formation of chlorine pentafluoride, which was also determined in this laboratory, it will be possible to report $E(Cl-F)$ bond energies for the sequence, $ClF$, $ClF_3$, and $ClF_5$. Note that the absolute values of these bond energies are strongly dependent on the value selected for the dissociation energy of fluorine.

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# A Review of Oscillator Strengths for Lines of Cu I

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New determinations of oscillator strengths made by Kock and Richter provide for the first time reference standards which permit the adjustment of five previous sets of measurements to an improved scale of absolute oscillator strengths for lines of Cu I. Critical discussions of the several sets of measurements and a consistent list of values for 272 lines in the region 2024 to 8092 Å are presented.

Key words: Atomic spectra; copper; Cu I; oscillator strengths; spectral lines of Cu I.

## 1. Introduction

Because of its superior electrical and thermal conductivity, relatively high melting point and strength, and its purity and cheapness in commerce, copper is widely used in electrical apparatus. It frequently serves as electrode material in various kinds of arcs and electrical discharges and its spectrum is on that account frequently observed in the laboratory. A good knowledge of the various physical constants associated with its spectrum leads to understanding of the discharges themselves. Although useful in the laboratory, the spectrum of copper is not well developed in stellar atmospheres, and is at present of limited astrophysical interest. About 20 lines of Cu I are observed in the solar spectrum.

The wavelengths and energy levels of the arc spectrum of copper have been thoroughly studied and determined by Shenstone [1948] but knowledge of the oscillator strengths of the lines, which is required if excitation conditions in discharges are to be measured and understood, is rather fragmentary. The reports of measurements are scattered throughout the literature, some of the measurements (my own included) are reduced to oscillator strengths with wrong temperatures, and the quantities reported differ in each report. Nevertheless, much of this data can be evaluated, corrected to proper temperatures, adjusted to an absolute scale, and tabulated in a useful and uniform fashion.

The framework on which this data can be reformed and assembled was provided by Kock and Richter [1966] when they measured 27 Cu I lines over the wavelength range 2618 to 5782 Å and energy level range 30535 to 64472 $cm^{-1}$. Their data provide lines over a wide enough range of energies to correct for erroneous temperatures used in earlier papers.

## 2. Published Data

A summary of the data critically reviewed in this paper is given in table 1. All of these measurements were made on relative scales; some were reported on absolute scales.

There are several papers of which the results are not included in this report. The early work at Utrecht by van Lingen [1936] and van den Bold [1945] on the two resonance lines, the six strong green and yellow lines, and the two infrared lines is now mainly of historical interest. Dickerman and Deuel [1964] have measured 12 lines in the blue region with a high-current free-burning arc in argon. Their results show serious and unsystematic disagreement with those of Kock and Richter and others. Riemann [1964] measured the six green and yellow lines and the two strong resonance lines in a wall-stabilized arc.

Ostroumenko and Rossikhin [1965] measured nine resonance lines between 2165 and 3274 Å in absorption with a furnace. Their value for the line at 2225 is an order of magnitude too low when compared with that of Slavenas [1966], who measured the same lines by the hook method. The same lines were also measured by Lvov [1970] using the method of atomic absorption in a flame. His value for the line at 2441 is an order of magnitude too high compared to the measurements of the other authors. With those two exceptions, the three sets of data are in good agreement.

An interesting paper by Vujnovic, Ivezic, and Tonejc-Mejaski [1968] included a few calculations according to Bates and Damgaard's coulomb approximation, which were in good agreement with Kock and Richter's experimental results. This prompted us to make further calculations of that kind, which are reported in section 4.

TABLE 1. *Published data on intensities and oscillator strengths in the first spectrum of copper* (Cu I)

| Reference | Date | No. of lines | Wavelength range | Energy level range | Type of experiment | Quantity reported |
|---|---|---|---|---|---|---|
| | | | Å | $cm^{-1}$ | | |
| Allen | 1932 | 27 | 4069–5641 | 62,403–64,472 | Arc in air | $I\lambda^4$ |
| Allen and Asaad | 1957 | 133 | 3247–5432 | 30,535–75,263 | Arc in air | log *gf* |
| Meggers, Corliss, and Scribner | 1961 | 46 | 2024–8092 | 30,535–71,291 | Arc in air | I |
| Corliss | 1963 | 180 | 2626–7154 | 30,535–79,116 | Arc in air | I |
| Slavenas | 1966 | 9 | 2165–3274 | 30,535–46,173 | Furnace | *f* |
| Corliss | 1967 | 13 | 2024–2441 | 40,944–58,691 | Arc in air | I |
| Kock and Richter | 1968 | 27 | 2618–5782 | 30,535–64,472 | Stabilized arc in Ar | A, log *gf* |

### 2.1. Kock and Richter [1968]

These authors have made the first comprehensive set of measurements of oscillator strengths for lines of Cu I in a light source operating under LTE conditions at accurately specified temperatures and electron densities. The plasma temperatures were determined from the absolute intensity of Ar I lines that have accurately known transition probabilities. The light source was of the wall-stabilized arc design originally developed at the University of Kiel by Maecker [1956]. A great deal of study has been devoted to methods of accurate temperature determination in this arc, both in Germany and in the United States. See, e.g., W. L. Wiese [1968]. The temperature determinations of other experiments discussed subsequently in this review are decidedly inferior and some are now known to be seriously in error.

Kock and Richter included among the 27 lines they measured the three lines which depopulate the $4p\ ^2P_{3/2}$ upper level of the strong resonance line at 3247 Å. The lifetime of this level has been recently determined by three independent experiments; Levin and Budick [1966], Ney [1966] and Cunningham and Link [1967]. The value 7.1 ns is within the uncertainty of all three measurements and has been adopted by Kock and Richter to put their relative values on an absolute scale. The data reported in this review have been adjusted to their scale.

Kock and Richter's data are listed in table 3 in the column headed KR. A typographical error in their value for the line at 4480.35 Å has been corrected. The values they gave for the two strong lines near 8000 Å they calculated with Bates and Damgaard's coulomb approximation.

### 2.2. Allen [1932]

The first quantitative intensity measurements in Cu I were made in 1932 by C. W. Allen at Canberra in the course of a study of the behavior of the relative intensity of the sharp and diffuse lines arising from the $5s\ ^4D$ term which lies above the first ionization potential of Cu I. The $^4D_{5/2}$ and $^4D_{3/2}$ levels are broad and decay mainly by autoionization. Allen measured the relative intensities of all 27 lines of the $4p\ ^4P^\circ - 5s\ ^4D$, $4p\ ^4F^\circ - 5s\ ^4D$, and $4p\ ^4D^\circ - 5s\ ^4D$ multiplets at various currents from 1 to 19 A in a free-burning copper arc in air at atmospheric pressure. He found that the broad lines increased in intensity relative to the sharp ones as the current was increased but that the ratio reached a constant value for currents above 12 A. These limiting relative intensities were in fair agreement with Russell's multiplet sum rules. At small currents (or at low electron densities) the broad lines disappear.

Of the 27 lines in these three multiplets, 8 have been measured by Kock and Richter. A least squares fit of a straight line to the plot $\log I\lambda^3/gf(\mathrm{KR})$ versus $E$ (upper) for these eight transitions provided the relationship by which oscillator strengths were calculated from Allen's intensities. The standard deviation of the points from the fitted line was [1] 0.18 dex (± 50 percent). These results are listed in table 3 in the column headed CWA.

### 2.3. Meggers, Corliss, and Scribner [1961]

In order to provide quantitative intensity data on a uniform scale for thousands of spectral lines of the metallic elements, Meggers, Corliss, and Scribner at NBS diluted each of 70 elements to the extent of one atom of each element in 1000 atoms of copper and observed the spectra radiated from a 10-A free-burning arc in air between electrodes of the copper. To observe the corresponding data for copper, silver was used as the electrode material. The intensities of the copper lines in the silver arc were brought onto the same scale as the lines of the other elements by including atoms of Au and Zn in the silver electrodes. At the time that the work was done, no method of calibrating the intensity scale below 2500 Å was available. Subsequently, Corliss [1967] applied a calibration to the lines below 2500 Å.

Of the 27 Cu I lines reported by Kock and Richter, 20 are found in these NBS Intensity Tables. To correlate the two sets of data we have plotted as open circles in figure 1, $\log (I\lambda^3)_{\mathrm{MCS}}/gf_{\mathrm{KR}}$ versus upper energy level for 18 of the lines. The two strong resonance lines at 3247 and 3274 Å have been omitted because of the possibility of systematic error in their intensity. They do not, however, deviate markedly from the least squares fitted line in the figure. The standard deviation of all the points in figure 1 from the line is 0.22 dex (±66%). Values of log *gf* were calculated from the intensities of the 46 Cu I lines in the NBS Intensity Tables by using the line in figure 1. They are reported in the column headed MCS in table 3.

[1] 0.18 dex = $10^{0.18}$.

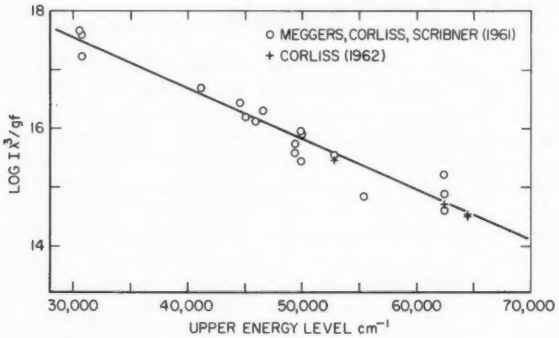


FIGURE 1. *Log ratio of intensity of copper lines in 10-ampere arcs times $\lambda^3$ to Kock and Richter's gf-values versus upper energy level.*

Open circles are for copper diluted 1/1000 in silver and crosses are for pure copper electrodes. Intensities from the silver arc have been multiplied by 1000.

### 2.4. Corliss [1962b]

To reduce the observations of Meggers, Corliss, and Scribner to a true scale of relative intensities, numerous lines of Cu I were selected to serve as reference standards of intensity. The relative power radiated by these lines was measured by comparison with a ribbon filament lamp and with a calibrated hydrogen continuum. The measurements were made by the methods of heterochromatic photographic photometry and are described in the NBS Tables. From 2 to 24 determinations were made on each of 207 lines of Cu I. The average number of determinations per line was 9 and the standard deviation of an individual determination is about 3 percent. The results for 180 lines were reported by Corliss [1962], who also calculated *gf*-values from the intensities using an arc temperature of 5100 K and a normalization function from Corliss and Bozman [1962]. Huber and Tobey [1968] and subsequently others have shown that this normalization function should in fact be a constant. Since this function changed more than two orders of magnitude between 50000 and 75000 $cm^{-1}$ and since Cu I is peculiar among the metallic atoms in that most of its lines originate at those high energies, Corliss' derived *gf*-values for Cu I are seriously in error.

The work of Kock and Richter provides an opportunity for an accurate reduction of Corliss' intensities to oscillator strengths. The intensity scale of the NBS Tables should be identical with that of Corliss [1962b] except for a factor 1000 arising from the dilution. The intensities from MCS were therefore multiplied by 1000 before plotting in figure 1. Four lines from Corliss' [1962b] list that are also in Kock and Richter are plotted as crosses in figure 1. It is remarkable that these four points fall accurately on the least squares line. We have, therefore, calculated *gf*-values from Corliss' [1962b] intensities with the same relationship used for MCS. Several lines reported by Corliss which arise from broad levels as noted by Shenstone are now omitted. The remaining 163 lines are found in table 3 in the column headed C.

### 2.5. Allen and Asaad [1957]

Allen and Asaad at the University of London Observatory measured oscillator strengths for numerous spectra by the method of dilution in copper electrodes, and in the course of their work they also measured oscillator strengths for about 130 Cu I lines. A few of the stronger lines were affected by self-absorption, but the remaining measurements seem to be of good quality. Unfortunately, the measurements were reduced with an arc temperature of 4300 K which was based primarily on oscillator strengths measured by R. B. King in an absorption furnace. It now seems, v. Garz and Kock [1969], that these early values are subject to systematic errors dependent on excitation potential. This same source of error affected the subsequent work of Corliss [1962a], who determined the temperature of his copper arc with numerous sets of furnace *f*-values. He derived a temperature of 5100 K, but the present comparison with the data of Kock and Richter in figure 1 shows that the correct value is more nearly 7000 K.

With this in mind, a readjustment of Allen and Asaad's results to the temperature scale of Kock and Richter has been made. There are 10 lines in common to the two lists, but eight of these arise from the $5s\,{}^4D$ term. To make a readjustment to the new temperature scale, a wider range of energy levels is required. It is preferable, therefore, to adjust Allen and Asaad's values with 63 lines in common with Corliss' list. These span a range of 35000 $cm^{-1}$ and provide a useful relationship for removing Allen and Asaad's systematic error. A linear least squares fit was made to a plot of log (AA/C) versus upper energy level. The standard deviation of the residuals is 0.11 dex (±30%). The corrected values are listed in table 3 in the column headed AA.

### 2.6. Slavenas [1966]

Slavenas measured relative oscillator strengths for nine resonance lines of Cu I by the hook method, using a vacuum furnace for his absorption cell. His values have been adjusted to the absolute scale adopted by Kock and Richter for the lines at 3247 and 3274 Å and are reported in the column headed S in table 3.

## 3. Absolute Scale

A thorough summary of recent determinations of absolute values for Cu I 3247 Å is given by Bell and Tubbs [1970]. Inspection of the 11 values determined since 1957 in their table 1 leaves little doubt that at present the best *f*-value for 3247 Å is 0.43 corresponding to log $gf = -0.07$. This is in excellent agreement with the value $-0.05$ adopted by Kock and Richter.

## 4. Coulomb Approximation

The success of Kock and Richter and of Vujnovic, Ivezic, and Tonejc-Mejaski in calculating good values for several Cu I lines by the method of Bates and Damgaard [1949] prompted me to apply that method to

19 of the lines measured by Kock and Richter. The results are given in table 2 and compared with the measured values. It is seen that, with the exception of the three lines involving the metastable $3d^9 4s^2\ ^2D$ term, the two sets of values show some agreement.

TABLE 2. *Values of log gf from the coulomb approximation (CA) compared with measured values (KR).*

| Wavelength | Configurations and Terms | | CA | KR |
|---|---|---|---|---|
| 3247.54 | $3d^{10}(^1S)4s\ ^2S_{1/2}$ | $-3d^{10}(^1S)4p\ ^2P^\circ_{3/2}$ | −0.01 | −0.05 |
| 3273.96 | $^2S_{1/2}$ | $-\ ^2P^\circ_{1/2}$ | −0.32 | −0.35 |
| 2961.16 | $3d^9 4s^2\ ^2D_{5/2}$ | $-3d^9 4s(^3D)4p\ ^2F^\circ_{7/2}$ | 0.09 | −1.40 |
| 3063.41 | $^2D_{3/2}$ | $-\ ^2P^\circ_{3/2}$ | −1.08 | −2.06 |
| 2824.37 | $^2D_{5/2}$ | $-\ ^2D^\circ_{5/2}$ | 0.14 | −1.25 |
| 5218.20 | $3d^{10}(^1S)4p\ ^2P^\circ_{3/2}$ | $-3d^{10}(^1S)4d\ ^2D_{5/2}$ | 0.30 | 0.27 |
| 5220.07 | $^2P^\circ_{3/2}$ | $-\ ^2D_{3/2}$ | −0.65 | −0.61 |
| 5153.23 | $^2P^\circ_{1/2}$ | $-\ ^2D_{3/2}$ | 0.04 | −0.01 |
| 4530.78 | $3d^{10}(^1S)4p\ ^2P^\circ_{3/2}$ | $-3d^{10}(^1S)6s\ ^2S_{1/2}$ | −1.38 | −1.28 |
| 4480.35 | $^2P^\circ_{3/2}$ | $-\ ^2S_{1/2}$ | −1.68 | −1.74 |
| 4062.64 | $3d^{10}(^1S)4p\ ^2P^\circ_{3/2}$ | $-3d^{10}(^1S)5d\ ^2D_{5/2}$ | −0.35 | −0.50 |
| 4022.63 | $^2P^\circ_{1/2}$ | $-\ ^2D_{3/2}$ | −0.61 | −0.73 |
| 4275.11 | $3d^9 4s(^3D)4p\ ^4P^\circ_{5/2}$ | $-3d^9 4s(^3D)5s\ ^4D_{7/2}$ | −0.35 | −0.12 |
| 4248.96 | $^4P^\circ_{1/2}$ | $-\ ^4D_{1/2}$ | −1.04 | −0.99 |
| 4651.12 | $3d^9 4s(^3D)4p\ ^4F^\circ_{9/2}$ | $-3d^9 4s(^3D)5s\ ^4D_{7/2}$ | −0.18 | −0.01 |
| 4704.59 | $^4F^\circ_{7/2}$ | $-\ ^4D_{7/2}$ | −1.11 | −0.83 |
| 4586.97 | $^4F^\circ_{7/2}$ | $-\ ^4D_{5/2}$ | −0.38 | −0.22 |
| 4539.70 | $^4F^\circ_{5/2}$ | $-\ ^4D_{3/2}$ | −0.51 | −0.69 |
| 4509.37 | $^4F^\circ_{3/2}$ | $-\ ^4D_{1/2}$ | −0.69 | 0.77 |

## 5. Results

The results of this review are tabulated in table 3. The wavelengths, estimated intensities and energy levels of the lines are taken from Shenstone [1948]. In the intensity column, R indicates lines easily reversed or self-absorbed in the arc and H, HH, or HHH indicates the degree of broadening depending on the nature of the upper levels. The next five columns contain the various sets of data reduced to the scale of Kock and Richter as discussed in section 2. The last column gives a value which, in my judgment, is the best. In many cases it is the only value, in some cases it is Kock and Richter's value, in some cases the mean value, and in a few cases a weighted mean.

The uncertainty assigned by Kock and Richter to their results lies between 12 and 20 percent. The comparisons made in section 2 of this paper suggest that the uncertainty of the remaining values cannot be less than 30 to 66 percent.

TABLE 3. *Values of log gf for lines of* Cu I.

| Wavelength | Intensity Estimate | Energy Levels | KR | S | MCS | C | AA | Best |
|---|---|---|---|---|---|---|---|---|
| Å | | $cm^{-1}$ | | | | | | |
| 2024.335 | 200R | 0–49383 | | | −0.48 | | | −0.48 |
| 2138.533 | 500R | 11203–57949 | | | −0.17 | | | −0.17 |
| 2165.093 | 1300R | 0–46173 | | −0.77 | −0.92 | | | −0.84 |
| 2178.944 | 1600R | 0–45879 | | −0.57 | −0.83 | | | −0.70 |
| 2181.720 | 1700R | 0–45821 | | −0.77 | −1.00 | | | −0.89 |
| 2199.583 | 1700R | 11203–56651 | | | −0.12 | | | −0.12 |
| 2199.752 | 1300R | 13245–58691 | | | −0.04 | | | −0.04 |
| 2214.581 | 1600R | 11203–56344 | | | −0.38 | | | −0.38 |
| 2225.697 | 2100R | 0–44916 | | −1.10 | −1.48 | | | −1.29 |
| 2227.775 | 1600R | 13245–58119 | | | 0.03 | | | 0.03 |
| 2230.084 | 2500R | 11203–56030 | | | −0.06 | | | −0.06 |
| 2244.265 | 2300R | 0–44544 | | −2.05 | | | | −2.05 |
| 2293.842 | 2500R | 11203–54784 | | | −0.77 | | | −0.77 |
| 2441.637 | 1000R | 0–40944 | | −2.35 | −2.53 | | | −2.44 |
| 2492.146 | 2000R | 0–40114 | | −1.91 | −1.87 | | | −1.89 |
| 2618.366 | 2500R | 11203–49383 | −0.90 | | −0.92 | | | −0.90 |
| 2626.678 | 10H | 40944–79003 | | | | −1.10 | | −1.10 |
| 2630.001 | 20H | 39019–77031 | | | | −1.05 | | −1.05 |
| 2634.933 | 30H | 39019–76959 | | | | −1.01 | | −1.01 |
| 2645.303 | 20H | 40114–77905 | | | | −1.47 | | −1.47 |
| 2649.840 | 30H | 40114–77841 | | | | −1.31 | | −1.31 |
| 2766.371 | 2500R | 13245–49383 | −1.36 | | −1.55 | | | −1.36 |
| 2824.370 | 1250R | 11203–46598 | −1.25 | | −0.98 | | | −1.25 |
| 2846.478 | 15 | 40944–76064 | | | | −1.97 | | −1.97 |
| 2858.225 | 50H | 39019–73995 | | | | −1.18 | | −1.18 |
| 2858.734 | 200 | 11203–46173 | | | | −3.48 | | −3.48 |
| 2882.934 | 1500 | 11203–45879 | | | −2.02 | | | −2.02 |
| 2890.84 | 50H | 44406–78988 | | | | −1.06 | | −1.06 |
| 2891.64 | 30H | 44544–79116 | | | | −1.11 | | −1.11 |
| 2931.699 | 10H | 40944–75044 | | | | −2.16 | | −2.16 |
| 2933.060 | 20 | 39019–73103 | | | | −1.90 | | −1.90 |
| 2961.165 | 2500R | 11203–44963 | −1.40 | | −1.38 | | | −1.40 |
| 2978.295 | 30H | 43514–77080 | | | | −0.92 | | −0.92 |
| 2979.380 | 25H | 43514–77068 | | | | −0.99 | | −0.99 |
| 2997.364 | 2000 | 13245–46598 | | | −2.00 | | | −2.00 |
| 2998.384 | 150 | 11203–44544 | | | | −3.84 | | −3.84 |
| 3010.838 | 2000 | 11203–44406 | | | −1.95 | | | −1.95 |
| 3012.005 | 250 | 40114–73305 | | | | −1.11 | | −1.11 |
| 3014.848 | 30H | 41153–74313 | | | | −1.49 | | −1.49 |
| 3021.544 | 300H | 40909–73995 | | | | −0.97 | | −0.97 |
| 3022.608 | 300H | 39019–72093 | | | | −1.16 | | −1.16 |
| 3030.258 | 10H | 40114–73105 | | | | −1.69 | | −1.69 |
| 3036.101 | 2500 | 13245–46173 | | | −1.84 | | | −1.84 |
| 3044.028 | 20H | 41153–73995 | | | | −1.67 | | −1.67 |
| 3052.554 | 15H | 41563–74313 | | | | −1.98 | | −1.98 |
| 3063.411 | 2500 | 13245–45879 | −2.06 | | −2.03 | | | −2.06 |
| 3068.906 | 15 | 13245–45821 | | | | −4.26 | | −4.26 |
| 3073.798 | 1400 | 11203–43726 | | | | −2.88 | | −2.88 |
| 3088.132 | 125 | 40944–73316 | | | | −1.13 | | −1.13 |
| 3093.989 | 1500 | 11203–43514 | | | −2.44 | | | −2.44 |

TABLE 3. *Values of log gf for lines of* Cu I. – Continued

| Wavelength | Intensity Estimate | Energy Levels | KR | S | MCS | C | AA | *Best |
|---|---|---|---|---|---|---|---|---|
| *Å* | | $cm^{-1}$ | | | | | | |
| 3099.928 | 1250 | 39019–71268 | | | | −0.53 | | −0.53 |
| 3113.482 | 50 | 39019–71128 | | | | −1.57 | | −1.57 |
| 3120.435 | 50H | 40114–72151 | | | | −1.48 | | −1.48 |
| 3126.109 | 1400H | 39019–70998 | | | | −0.35 | | −0.35 |
| 3128.701 | 650H | 40114–72067 | | | | −0.71 | | −0.71 |
| 3140.312 | 400H | 39019–70853 | | | | −0.99 | | −0.99 |
| 3142.444 | 750H | 40114–71927 | | | | −0.57 | | −0.57 |
| 3146.821 | 450H | 40114–71883 | | | | −0.83 | | −0.83 |
| 3148.333 | 3 | 41563–73316 | | | | −1.98 | | −1.98 |
| 3149.508 | 30 | 41563–73305 | | | | −1.61 | | −1.61 |
| 3156.629 | 450 | 13245–44916 | | | | −3.27 | | −3.27 |
| 3160.047 | 25 | 41563–73199 | | | | −1.59 | | −1.59 |
| 3169.681 | 500H | 41563–73103 | | | | −0.69 | | −0.69 |
| 3171.663 | 5H | 44544–76064 | | | | −1.66 | | −1.66 |
| 3194.099 | 1500 | 13245–44544 | −2.02 | | −1.80 | | | −2.02 |
| 3208.231 | 1400 | 13245–44406 | | | −2.31 | | | −2.31 |
| 3223.435 | 400H | 42302–73316 | | | | −0.89 | | −0.89 |
| 3224.664 | 450H | 42302–73305 | | | | −0.80 | | −0.80 |
| 3231.178 | 650H | 41153–72093 | | | | −0.63 | | −0.63 |
| 3233.899 | 450H | 41153–72067 | | | | −1.11 | | −1.11 |
| 3235.713 | 650H | 42302–73199 | | | | −0.38 | | −0.38 |
| 3243.164 | 1500H | 41153–71979 | | | | −0.15 | | −0.15 |
| 3247.540 | 10000R | 0–30784 | −0.05 | −0.05 | −0.22 | | | −0.05 |
| 3268.278 | 650H | 41563–72151 | | | | −0.67 | | −0.67 |
| 3273.957 | 10000R | 0–30535 | −0.35 | −0.36 | −0.53 | | | −0.35 |
| 3279.815 | 2000 | 13245–43726 | | | −2.14 | | | −2.14 |
| 3282.716 | 1400H | 41563–72017 | | | | −0.27 | | −0.27 |
| 3290.541 | 1500H | 40909–71291 | | | | −0.19 | | −0.19 |
| 3292.393 | 125H | 41563–71927 | | | | −1.25 | | −1.25 |
| 3292.827 | 650 | 11203–41563 | | | | −3.22 | | −3.22 |
| 3307.948 | 2500H | 40909–71131 | | | 0.64 | | | 0.64 |
| 3317.218 | 750 | 41153–71291 | | | | −0.49 | | −0.49 |
| 3319.682 | 150 | 41153–71268 | | | | −0.68 | −0.64 | −0.66 |
| 3329.636 | 225 | 41153–71178 | | | | −1.05 | −1.04 | −1.04 |
| 3335.215 | 400 | 41153–71128 | | | | −1.04 | −1.02 | −1.03 |
| 3337.845 | 1500 | 11203–41153 | −2.29 | | −2.10 | | −2.68 | −2.29 |
| 3349.279 | 450H | 42302–72151 | | | | −0.73 | −0.52 | −0.62 |
| 3354.474 | 60HH | 42302–72104 | | | | | −0.96 | −0.96 |
| 3365.342 | 750H | 41153–70860 | | | | −0.54 | −0.56 | −0.55 |
| 3375.672 | 30H | 41563–71178 | | | | −1.52 | −1.42 | −1.47 |
| 3381.421 | 200H | 41563–71128 | | | | −0.86 | −0.62 | −0.74 |
| 3384.80 | 15H | 41563–71098 | | | | | −1.47 | −1.47 |
| 3392.016 | 8H | 43726–73199 | | | | −1.87 | | −1.87 |
| 3396.324 | 10H | 41563–70998 | | | | −1.79 | −1.98 | −1.88 |
| 3413.343 | 200H | 45821–75109 | | | | −0.92 | | −0.92 |
| 3420.166 | 8H | 45879–75109 | | | | | −1.48 | −1.48 |
| 3433.972 | 3H | 30535–59647 | | | | | −3.30 | −3.30 |
| 3436.543 | 5H | 46173–75263 | | | | | −1.41 | −1.41 |
| 3440.507 | 250 | 13245–42302 | | | | −3.60 | | −3.60 |
| 3457.850 | 750 | 11203–40114 | | | | −3.31 | −3.50 | −3.40 |

TABLE 3. *Values of log gf for lines of* Cu I. – Continued

| Wavelength | Intensity Estimate | Energy Levels | KR | S | MCS | C | AA | Best |
|---|---|---|---|---|---|---|---|---|
| Å | | $cm^{-1}$ | | | | | | |
| 3459.428 | 25H | 44406–73305 | | | | −1.44 | −1.48 | −1.46 |
| 3463.499 | 5HH | 30784–59647 | | | | | −2.65 | −2.65 |
| 3472.141 | 200H | 44406–73199 | | | | −1.08 | −1.02 | −1.05 |
| 3474.578 | 5 | 44544–73316 | | | | −1.78 | −1.94 | −1.86 |
| 3475.999 | 750H | 44544–73305 | | | | −0.42 | | −0.42 |
| 3481.614 | 5 | 30535–59249 | | | | | −1.67 | −1.67 |
| 3483.761 | 1250H | 44406–73103 | | | | −0.27 | | −0.27 |
| 3487.566 | 60H | 46598–75263 | | | | | −1.21 | −1.21 |
| 3488.858 | 100H | 44544–73199 | | | | −1.22 | −1.24 | −1.23 |
| 3498.063 | 125H | 43514–72093 | | | | −1.25 | −1.22 | −1.24 |
| 3500.324 | 50H | 44544–73105 | | | | −1.28 | | −1.28 |
| 3507.407 | 5H | 43514–72017 | | | | −1.67 | −0.94 | −1.67 |
| 3512.121 | 650H | 43514–71979 | | | | −0.48 | | −0.48 |
| 3517.039 | 100H | 43726–72151 | | | | −1.25 | −1.42 | −1.34 |
| 3520.031 | 500 | 44916–73316 | | | | −0.54 | | −0.54 |
| 3524.231 | 1250 | 43726–72093 | | | | −0.31 | | −0.31 |
| 3527.482 | 500 | 43726–72067 | | | | −0.65 | −0.71 | −0.68 |
| 3530.383 | 2000 | 13245–41563 | | | | −2.60 | −2.67 | −2.64 |
| 3533.746 | 500 | 43726–72017 | | | | −0.66 | −0.57 | −0.62 |
| 3544.963 | 125H | 43726–71927 | | | | −1.11 | −1.12 | −1.12 |
| 3546.433 | 15H | 44916–73105 | | | | −1.52 | −1.54 | −1.53 |
| 3566.131 | 5HH | 30535–58568 | | | | | −2.31 | −2.31 |
| 3594.023 | 30 | 11203–39019 | | | | −4.22 | −4.31 | −4.26 |
| 3599.132 | 1400 | 43514–71291 | | | 0.40 | | | 0.40 |
| 3602.032 | 1400 | 43514–71268 | | | 0.40 | | −0.38 | 0.40 |
| 3609.295 | 200 | 13245–40944 | | | | −3.84 | | −3.84 |
| 3610.809 | 200 | 44406–72093 | | | | −1.03 | −1.04 | −1.04 |
| 3613.761 | 600 | 43514–71178 | | | | −0.62 | −0.62 | −0.62 |
| 3614.218 | 200 | 44406–72067 | | | | −0.96 | −1.04 | −1.00 |
| 3620.352 | 225 | 43514–71128 | | | | −1.06 | −1.15 | −1.10 |
| 3621.245 | 600 | 44544–72151 | | | | −0.61 | −0.62 | −0.62 |
| 3624.236 | 100 | 43514–71098 | | | | | −1.12 | −1.12 |
| 3627.32 | 125HH | 44544–72104 | | | | | −0.68 | −0.68 |
| 3629.771 | 10 | 43726–71268 | | | | −1.77 | | −1.77 |
| 3632.558 | 50 | 44406–71927 | | | | | −1.23 | −1.23 |
| 3635.916 | 250 | 45821–73316 | | | | −0.78 | −0.77 | −0.78 |
| 3641.693 | 50 | 43726–71178 | | | | −1.23 | −1.30 | −1.26 |
| 3645.232 | 250 | 45879–73305 | | | | −0.94 | −1.00 | −0.97 |
| 3648.383 | 125 | 43726–71128 | | | | −1.29 | −1.40 | −1.35 |
| 3650.855 | 5 | 44544–71927 | | | | | −1.66 | −1.66 |
| 3652.34 | 100H | 43726–71098 | | | | | −0.58 | −0.58 |
| 3655.859 | 600H | 43514–70860 | | | | −0.78 | −0.92 | −0.85 |
| 3656.785 | 125H | 44544–71883 | | | | −1.13 | −1.24 | −1.18 |
| 3659.353 | 125H | 45879–73199 | | | | −1.03 | −1.11 | −1.07 |
| 3665.735 | 125H | 43726–70998 | | | | −1.31 | −1.43 | −1.37 |
| 3671.953 | 100H | 45879–73105 | | | | −1.12 | −1.14 | −1.13 |
| 3687.438 | 400 | 30784–57895 | | | | | −0.82 | −0.82 |
| 3695.358 | 8H | 44963–72017 | | | | −1.65 | −2.03 | −1.65 |
| 3699.097 | 10H | 46173–73199 | | | | −1.55 | −1.72 | −1.64 |

TABLE 3. *Values of log gf for lines of* Cu I.

| Wave-length | Intensity Estimate | Energy Levels | KR | CWA | MCS | C | AA | Best |
|---|---|---|---|---|---|---|---|---|
| *Å* | | $cm^{-1}$ | | | | | | |
| 3700.536 | 250H | 44963–71979 | | | | −0.92 | | −0.92 |
| 3712.009 | 30H | 46173–73105 | | | | −1.27 | −1.22 | −1.24 |
| 3720.771 | 150 | 13245–40114 | | | | −3.99 | −4.03 | −4.01 |
| 3721.666 | 8H | 44406–71268 | | | | −1.78 | −1.69 | −1.74 |
| 3734.180 | 200H | 44406–71178 | | | | −1.14 | −1.11 | −1.12 |
| 3741.242 | 450H | 44406–71128 | | | | −0.89 | −0.90 | −0.90 |
| 3745.356 | 20H | 44406–71098 | | | | | −1.11 | −1.11 |
| 3759.492 | 60 | 44406–70998 | | | | −1.30 | −1.46 | −1.38 |
| 3764.837 | 5H | 44544–71098 | | | | | −1.76 | −1.76 |
| 3771.904 | 100H | 46598–73103 | | | | −1.04 | −0.99 | −1.02 |
| 3780.045 | 5H | 44406–70853 | | | | | −1.90 | −1.90 |
| 3797.245 | 8 | 44963–71291 | | | | | −1.81 | −1.81 |
| 3799.88 | 10H | 44544–70853 | | | | −1.68 | −1.49 | −1.58 |
| 3800.502 | 30H | 44963–71268 | | | | −1.34 | −1.36 | −1.35 |
| 3805.232 | 100H | 45879–72151 | | | | −1.11 | | −1.11 |
| 3811.95 | 8HH | 45879–72104 | | | | | −1.39 | −1.39 |
| 3813.542 | 10 | 44963–71178 | | | | −1.69 | −1.63 | −1.66 |
| 3817.490 | 5 | 45879–72067 | | | | | −1.93 | −1.93 |
| 3820.884 | 60 | 44963–71128 | | | | −1.27 | −1.84 | −1.27 |
| 3825.047 | 100H | 30535–56671 | | | | | −1.84 | −1.84 |
| 3837.976 | 5 | 45879–71927 | | | | −1.91 | −1.98 | −1.94 |
| 3860.472 | 600 | 44963–70860 | | | | −0.67 | −0.60 | −0.64 |
| 3881.714 | 5 | 46173–71927 | | | | −1.76 | | −1.76 |
| 3888.40 | 4H | 46173–71883 | | | | | −1.87 | −1.87 |
| 3921.267 | 5 | 46598–72093 | | | | −1.43 | −1.40 | −1.42 |
| 3925.274 | 8 | 46598–72067 | | | | −1.36 | −1.29 | −1.33 |
| 3933.027 | 5 | 46598–72017 | | | | −1.65 | | −1.65 |
| 3946.938 | 3 | 46598–71927 | | | | −1.88 | −1.81 | −1.84 |
| 3951.616 | 2 | 45879–71178 | | | | −2.30 | | −2.30 |
| 3964.16 | 5H | 45879–71098 | | | | | −1.70 | −1.70 |
| 3975.7 | 5HHH | 40114–65260 | | | | | −1.73 | −1.73 |
| 3979.954 | 5 | 45879–70998 | | | | −2.11 | −2.19 | −2.15 |
| 3993.692 | 0 | 45821–70853 | | | | −2.46 | | −2.46 |
| 3998.018 | 3 | 46173–71178 | | | | −2.13 | | −2.13 |
| 4003.028 | 15 | 45879–70853 | | | | −1.43 | −1.45 | −1.44 |
| 4010.836 | 8H | 46173–71098 | | | | | −1.93 | −1.93 |
| 4015.8 | 10HHH | 30535–55429 | | | | | −2.49 | −2.49 |
| 4022.629 | 1250 | 30535–55388 | −0.73 | | −1.13 | | | −0.73 |
| 4027.026 | 10 | 46173–70998 | | | | −1.42 | | −1.42 |
| 4050.617 | 20H | 46173–70853 | | | | −1.45 | −1.59 | −1.52 |
| 4052.380 | 2 | 46598–71268 | | | | −1.39 | −1.78 | −1.78 |
| 4062.641 | 2000 | 30784–55391 | −0.50 | | | | | −0.50 |
| 4069.53 | 6HH | 39019–63585 | | −2.59 | | | | −2.59 |
| 4073.224 | 20HHH | 40114–64657 | | | | | −1.59 | −1.59 |
| 4075.572 | 50 | 46598–71128 | | | | −0.96 | −1.00 | −0.98 |
| 4080.534 | 15H | 46598–71098 | | | | | −1.12 | −1.12 |
| 4104.218 | 25 | 40114–64472 | | −1.95 | | −1.75 | −1.62 | −1.77 |
| 4111.4 | 3HHH | 40944–65260 | | | | | −1.71 | −1.71 |
| 4121.74 | 10 | 46598–70853 | | | | −1.55 | −1.54 | −1.54 |
| 4123.287 | 30H | 43726–67971 | | | | | −1.32 | −1.32 |

TABLE 3. *Values of log gf for lines of* Cu I.—Continued

| Wavelength | Intensity Estimate | Energy Levels | KR | CWA | MCS | C | AA | Best |
|---|---|---|---|---|---|---|---|---|
| Å | | $cm^{-1}$ | | | | | | |
| 4177.758 | 100HH | 39019–62948 | | −1.30 | | | −1.05 | −1.18 |
| 4230.9 | 5HHH | 43514–67142 | | | | | −1.57 | −1.57 |
| 4242.26 | 30H | 44406–67971 | | | | | −1.45 | −1.45 |
| 4248.956 | 150 | 40944–64472 | −0.99 | −1.12 | | −1.00 | −0.92 | −0.99 |
| 4259.401 | 150HHH | 40114–63585 | | −1.19 | | | | −1.19 |
| 4275.107 | 950 | 39019–62403 | −0.12 | −0.39 | −0.11 | | −0.37 | −0.12 |
| 4328.68 | 20HH | 41563–64657 | | | | | −1.79 | −1.79 |
| 4336.00 | 10H | 44916–67971 | | | | | −1.77 | −1.77 |
| 4354.74 | 10HHH | 42302–65260 | | | | | −1.55 | −1.55 |
| 4378.20 | 550HH | 40114–62948 | | −0.62 | | | −0.44 | −0.53 |
| 4415.54 | 200HH | 40944–63585 | | −1.03 | | | −0.78 | −0.90 |
| 4480.350 | 500 | 30535–52849 | −1.74 | | | −1.81 | −1.53 | −1.74 |
| 4507.35 | 200HHH | 44963–67142 | | | | | −0.34 | −0.34 |
| 4509.374 | 400 | 42302–64472 | −0.77 | −0.76 | | −0.75 | −0.68 | −0.77 |
| 4525.112 | 40H | 45879–67971 | | | | | −1.25 | −1.25 |
| 4530.785 | 800 | 30784–52849 | −1.28 | | −1.20 | | | −1.28 |
| 4539.695 | 800HH | 41563–63585 | −0.69 | −0.46 | | | −0.50 | −0.69 |
| 4586.97 | 1300HH | 41153–62948 | −0.22 | −0.27 | | | −0.19 | −0.22 |
| 4642.58 | 150HHH | 43726–65260 | | | | | −0.81 | −0.81 |
| 4651.124 | 2000 | 40909–62403 | −0.01 | −0.09 | 0.30 | | 0.04 | −0.01 |
| 4674.72 | 500HH | 41563–62948 | | −0.71 | | | −0.56 | −0.64 |
| 4697.490 | 350HH | 42302–63585 | | −0.86 | | | −0.86 | −0.86 |
| 4704.594 | 450 | 41153–62403 | −0.83 | −0.76 | | −0.81 | −0.60 | −0.83 |
| 4767.49 | 75HHH | 46173–67142 | | | | | −0.81 | −0.81 |
| 4776.22 | 20HH | 43726–64657 | | | | | −1.59 | −1.59 |
| 4797.042 | 20 | 41563–62403 | | −2.07 | | −2.07 | | −2.07 |
| 4842.290 | 25H | 42302–62948 | | −1.84 | | | −1.68 | −1.76 |
| 4866.10 | 75HHH | 46598–67142 | | | | | −0.49 | −0.49 |
| 5016.611 | 400 | 44544–64472 | | −0.79 | | −0.99 | −0.81 | −0.86 |
| 5034.36 | 100HH | 43726–63585 | | | | | −0.86 | −0.86 |
| 5076.173 | 100HH | 44963–64657 | | | | | −0.55 | −0.55 |
| 5105.541 | 1500 | 11203–30784 | −1.51 | | −1.73 | | | −1.51 |
| 5111.913 | 300 | 44916–64472 | | −0.98 | | −1.19 | −0.94 | −1.04 |
| 5144.120 | 550H | 43514–62948 | | −0.69 | | | −0.64 | −0.66 |
| 5153.235 | 2000 | 30535–49935 | −0.01 | | −0.29 | | | −0.01 |
| 5200.87 | 500H | 43726–62948 | | | | | −0.77 | −0.77 |
| 5212.780 | 140H | 44406–63585 | | −1.29 | | | | −1.29 |
| 5218.202 | 2500 | 30784–49942 | 0.27 | | 0.40 | | | 0.27 |
| 5220.070 | 500 | 30784–49935 | −0.61 | | −0.38 | | | −0.61 |
| 5250.52 | 500HH | 44544–63585 | | −0.75 | | | −0.74 | −0.74 |
| 5292.517 | 1650 | 43514–62403 | −0.44 | −0.23 | 0.16 | | −0.16 | −0.44 |
| 5352.666 | 300 | 43726–62403 | | | | −1.67 | | −1.67 |
| 5354.95 | 250HH | 44916–63585 | | −1.02 | | | −1.09 | −1.06 |
| 5360.030 | 200 | 45821–64472 | | | | −1.70 | | −1.70 |
| 5376.867 | 5 | 45879–64472 | | | | −2.29 | | −2.29 |
| 5391.62 | 450HH | 44406–62948 | | −0.81 | | | −0.69 | −0.75 |
| 5432.05 | 250HH | 44544–62948 | | −1.06 | | | −0.93 | −1.00 |
| 5463.138 | 150 | 46173–64472 | | | | −1.86 | | −1.86 |
| 5554.935 | 100 | 44406–62403 | | −1.48 | | −1.78 | | −1.63 |
| 5700.240 | 1500 | 13245–30784 | −2.34 | | −2.18 | | | −2.34 |

TABLE 3. *Values of log gf for lines of* Cu I. – Continued

| Wavelength | Intensity Estimate | Energy Levels | KR | CWA | MCS | C | AA | Best |
|---|---|---|---|---|---|---|---|---|
| *Å* | | $cm^{-1}$ | | | | | | |
| 5732.325 | 75 | 44963–62403 | | | | −1.82 | | −1.82 |
| 5782.132 | 1500 | 13245–30535 | −1.78 | | −1.59 | | | −1.78 |
| 6223.66 | 4 | 56030–72093 | | | | −1.33 | | −1.33 |
| 6325.45 | 5 | 46598–62403 | | | | −2.22 | | −2.22 |
| 6474.20 | 10 | 56651–72093 | | | | −1.17 | | −1.17 |
| 6485.18 | 5 | 56651–72067 | | | | −1.34 | | −1.34 |
| 6506.14 | 0 | 56651–72017 | | | | −1.95 | | −1.95 |
| 6544.51 | 1 | 56651–71927 | | | | −1.75 | | −1.75 |
| 6550.98 | 1 | 56030–71291 | | | | −1.86 | | −1.86 |
| 6583.54 | 0H | 58119–73305 | | | | −1.66 | | −1.66 |
| 6599.68 | 0H | 56030–71178 | | | | −1.95 | | −1.95 |
| 6621.61 | 30H | 56030–71128 | | | | −1.00 | | −1.00 |
| 6629.67 | 5H | 58119–73199 | | | | −1.52 | | −1.52 |
| 6672.23 | 10 | 58119–73103 | | | | −0.91 | | −0.91 |
| 6741.42 | 100 | 56030–70860 | | | | −0.47 | | −0.47 |
| 6881.94 | 10 | 56651–71178 | | | | −1.52 | | −1.52 |
| 6890.90 | 10 | 57419–71927 | | | | −1.45 | | −1.45 |
| 6905.94 | 100 | 56651–71128 | | | | −0.78 | | −0.78 |
| 6968.34 | 5 | 56651–70998 | | | | −1.84 | | −1.84 |
| 7154.29 | 5 | 58119–72093 | | | | −1.64 | | −1.64 |
| 7933.130 | 1500 | 30535–43137 | −0.60 | | −0.34 | | | −0.47 |
| 8092.634 | 2000 | 30784–43137 | −0.30 | | −0.02 | | | −0.16 |

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# Stark Effect and Hyperfine Structure of HCN Measured With an Electric Resonance Maser Spectrometer

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The 449 MHz *l*-type doubling spectrum of HCN has been measured to high precision with a molecular beam maser spectrometer. Hyperfine structure due to both the nitrogen nucleus and the proton was resolved, and the coupling constant of the proton $\mathbf{I} \cdot \mathbf{J}$ interaction was found to be $-27.3 \pm 1.6$ kHz. The spectrometer is also suited to precise measurements of Stark effects in molecules of the linear and symmetric top variety, and Stark shifts of up to $10^4$ times the zero-field line width have been measured in the HCN spectrum. Analysis of these measurements yields the value $\mu = 2.940 \pm 0.001$ D for the dipole moment of the $v_2 = 1$ state of HCN.

Key words: Dipole moment; HCN resonance spectrum; maser spectrometer; Stark effect; voltage standard.

## 1. Introduction

An electric resonance spectrometer is a microwave spectrometer tuned by the molecular Stark effect: A variable electric field, in an electrode structure called a Stark cell, is used to bring spectral lines into resonance, one at a time, with a fixed-frequency oscillator. It is essential that the electric field be uniform and exactly related to the applied voltage. When, as is customary, the Stark cell has the form of a parallel plate capacitor, the critical factors are the flatness, parallelism, and cleanliness of the two plates, and the thermal stability of their mounting. The best such Stark cells have been made from metallized optical flats, separated by ground quartz spacers and mounted in vacuum [1].[1]

Given a uniform and stable Stark field, the chief remaining design problem of an electric resonance spectrometer is that of superposing a radio frequency or microwave alternating field on the d-c Stark field. Furthermore, if molecules enter the uniform field through a region of nonuniform field, as at the edges of a parallel plate capacitor, the alternating field must be excluded from such regions. This injecting and shaping of alternating fields has been done in two ways: For work at radio frequencies, lines can be scratched in the metal coating of the optical flats, making a pattern of radio frequency electrodes and guards which, when connected to a source oscillator, excite the radio frequency field and confine it to the correct region [2]. For work at high microwave frequencies the Stark electrodes can double as a parallel plate waveguide or Fabry-Perot resonator [3, 4], microwave energy being fed in and confined by an array of coupling holes, or horns and lenses.

These methods have their disadvantages. The radio frequency method requires a conventional molecular beam spectrometer, a complex apparatus, and is difficult to use at the high frequencies that correspond to large Stark shifts. Of the high frequency methods, the Fabry-Perot resonator works well in a simple microwave absorption spectrometer but suffers from the fact that the spacing of the plates determines their microwave properties as well as the strength and uniformity of the Stark field. The parallel plate waveguide cell has not been tried, but probably would give sufficient resolution only in a molecular beam apparatus, since molecules would have to be kept out of the edge regions where the microwave beam enters and leaves the Stark cell.

This paper describes a new type of electric resonance spectrometer, one in which the Stark cell is made into a half-wave parallel line resonator. While providing a convenient distribution of radio frequency field strength, this type of Stark cell is free of the high frequency limitation of the electrode-and-guard method and also free of the spacing sensitivity of the Fabry-Perot method. A novel $Q$-enhancing technique permits the spectrometer to be operated as a beam maser, an apparatus that offers the high resolution of a conventional molecular beam spectrometer with considerable reduction in its complexity.

As a test molecule for the electric resonance maser, HCN was chosen. Microwave absorption measurements [5] had established the frequencies of its UHF spectrum with fair precision, and the Stark effect of

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[1] Figures in brackets indicate the literature references at the end of this paper.

this spectrum was expected to be both large and easy to interpret. Since completing observations on the HCN spectrum, we have learned of similar work at Harvard University by Tomasevich and Klemperer [6], with a conventional molecular beam apparatus. Together with observations on the low radio-frequency Stark spectra of HCN and DCN, they report observations on the UHF spectrum of HCN which are essentially identical to those reported here, and of equal precision.

## 2. Apparatus

The mechanics of molecular beam masers are well known, and need be mentioned only briefly. Gas molecules effuse into a high vacuum vessel and a fraction of them, those entering in roughly the right direction and occupying certain energy states, are focused into a beam by an electrostatic state selector, a cylindrical bundle of rods wired to give a high potential difference between each adjacent pair of rods. The unfocused majority of molecules is removed, either by vacuum pumps or, in the case of condensible gases like HCN, by the more economical means of a cold trap. The state selector—cold trap assembly of the present maser was constructed by H. Takuma, for original service in a low radio frequency beam maser [7]. Vacuum pumping for the entire system is done by a single 4-in oil diffusion pump.

From the state selector, the beam passes into a high-$Q$ resonator, which is driven at its resonance frequency by an rf oscillator. If this frequency is tuned to the energy separation of two molecular states, one of which is focused and the other not, then transitions induced in the beam molecules by the rf field will change the energy density within the resonator, and this change can be detected by a sensitive receiver coupled to the resonator. As in the conventional molecular beam spectrometer, the minimum width of the resonance line is determined by the time of flight of a typical beam molecule through the resonator, and is very small, a few kHz or less.

### 2.1. Waveguide-Shielded Linear Resonators

Because of their propensity to radiate, parallel transmission lines and other linear resonators ordinarily make poor, low $Q$ resonators at UHF and higher frequencies, but this failing can be corrected through an elegant stratagem devised by Halford [8]. The principle is to prevent the resonator from radiating by depriving it of electromagnetic field modes which can accept its radiation. Although this might seem difficult to do, it is not. One simply puts the resonator into a section of rectangular waveguide which is small enough to support only one mode of propagation, the so-called dominant mode, and then one orients the resonator so that its radiation field is orthogonal to the waveguide field. Actually, perfect orthogonality of the two fields is not possible nor is it desirable, since a residual coupling is useful for exciting the resonator and for monitoring its behavior. Halford, working with helical resonators at X-band frequencies, used the waveguide simultaneously as a transmission line for this purpose. At lower frequencies, where long runs of waveguide are awkward, it is equally effective to short-circuit both ends of the waveguide and couple to its internal field with electric probes and coaxial cables.

We have found that a variety of unlikely looking metal shapes become high-$Q$ resonators when placed inside the waveguide. A straight wire dipole, the sort of thing often used as an antenna because of its efficiency as a radiator, becomes a half-wave resonator with a $Q$ of several thousand. Bent into a helical coil, the dipole retains most of its $Q$ and works well as a miniature cavity for paramagnetic resonance experiments [9]. Other high-$Q$ resonators include half-wave lengths of wire or strip stock bent into semicircular form, and full wavelengths bent into circular form, and also the parallel line shapes that these curved resonators take when flattened. Tests conducted at UHF and S-band frequencies on these various shapes, made of copper and with dimensions scaled according to the wavelength, showed no strong dependence of the $Q$ on frequency. The highest $Q$'s were measured for resonators made of thin strip stock, approximately 1/8 wavelength wide, supported well away from the waveguide walls by dielectric posts which were attached to the resonators at voltage node points. When oriented so as to couple very lightly to the waveguide field, these strip resonators had $Q$'s of 6000 or more. Except for the parallel-line types, where line spacings less than about 1/30 wavelength were deleterious, the shape of the strip resonators had no effect on the $Q$.

### 2.2. The Stark Cell Resonator

Metallized glass flats are lossy at UHF frequencies, and it seemed unlikely that a resonator of reasonable $Q$ could be made out of a traditional Stark cell, even though the geometry was roughly correct. Instead, the resonator was made from two rectangular slabs of solid aluminum, $2.5 \times 10 \times 20$ cm, ground flat to $\pm 2 \times 10^{-5}$ cm over their entire inner surfaces. The slabs were cross-cut from a 30 cm diam billet of type 2024 aluminum, stress-relieved, and ground under the supervision of S. Gerner in the NBS optical shop. The aluminum flats are mounted with their 10 cm dimension vertical, separated by four quartz spacers ground to a length of $1.00000 \pm 0.00005$ cm. Light spring pressure establishes the contact between flats and spacers. Folded quarter-wave lines, made of copper sheet interleaved with PTFE, are mounted near the ends of the flats and make spring-finger contact with them. By providing rf short circuits while maintaining d-c insulation, these folded lines make the assembly into a half-wave resonator and still permit d-c voltages to be applied to the flats. A half-wave resonator is used, in spite of its somewhat inconvenient length as compared to a quarter-wave resonator, because of its more favorable rf field distribution. The rf electric field intensity is zero at the two ends of a half-wave resonator and is weak for a considerable distance inward. Hence, beam molecules are unlikely to undergo rf transitions in the two end regions, where the fringing component of the d-c field is appreciable. Fringing fields from the edges



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of the resonator, and local field perturbations due to the quartz spacers, are kept away from the molecular beam path by making the aluminum flats broad as compared to the gap width.

Figure 1 shows how the resonator is positioned within its vacuum vessel, a 15 cm i.d. Pyrex tube, and its waveguide shield box. The support structure, a nylon and Pyrex cage, is omitted for clarity. Beam molecules, entering from the state selector on the left, travel lengthwise between the resonator plates, eventually collide with them, and are pumped away. To resonate at 475 MHz, a convenient frequency for the HCN electric resonance observations, the resonator must have a length of about 28 cm. The extra 8 cm is provided by copper sheet extensions, soldered to the right-hand folded line and making spring-finger contact with the aluminum flats.

The shield box shown in figure 1 is a length of WR 1800 waveguide, short-circuited at each end, and split along the zero-current line for convenient installation. The dimensions of the box are such that all of its rectangular mode resonances lie above 600 MHz. The waveguide field is excited by an electric probe, the upper one shown in figure 1, and may be oriented with respect to the resonator field by rotating the entire shield box on its two support flanges. Sufficient coupling between the two fields ordinarily results when the box is positioned 10 to 20 deg from the horizontal. The lower probe shown in figure 1 is the signal detecting probe. With its perpendicular mounting it is insensitive to the waveguide field, but it is made long enough to pick up the resonator field with approximately critical coupling.

Designed mainly to give d-c field uniformity, the Stark cell resonator violates several of the design rules mentioned above for high-$Q$ linear resonators, especially those concerning plate thickness and separation, and the absence of lossy material nearby. The measured $Q$, with the shield box positioned for approximately critical coupling, is 500, while under similar conditions the copper strip resonators have a $Q$ of 3000. Since the sensitivity of a maser spectrometer depends not linearly but rather on the square root of the $Q$ [10], this is not too serious a loss. Indications are that the $Q$ could be doubled, at no cost in d-c field uniformity, by replacing the Pyrex vacuum vessel with one made of quartz or other low-loss glass.

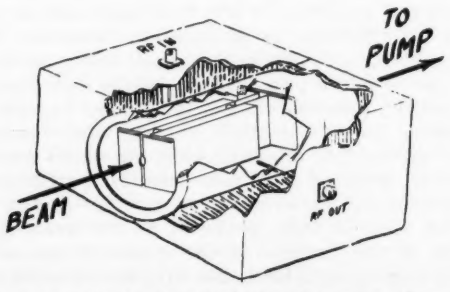


FIGURE 1. *Simplified view of the Stark cell resonator, glass vacuum vessel, and waveguide shield.*

### 2.3. Spectrometer Circuits

The HCN spectrum lies at the upper end of the half-meter amateur communication band, and can be detected with a standard communciations receiver preceded by a UHF converter. With minor retuning, a Parks half-meter converter [11],[2] an inexpensive transistor unit with a rated noise figure of 4 dB, was found to give adequate sensitivity. The converter input is connected directly to the lower probe of the waveguide shield (fig. 1) by a short coaxial line. A commercial phase-locked UHF signal generator, connected to the upper probe, supplies excitation at a stabilized frequency to the waveguide field.

A state selector voltage of 15 kV, sufficient for saturated focusing behavior, is produced by two 7.5 kV rf-type power supplies of opposite polarity. A mercury-wetted relay driven by an audio oscillator turns these power supplies on and off at a 25 Hz rate by interrupting the cathode circuits of their rf oscillators, and thereby imparts a square wave modulation to the focused beam intensity. This modulation method permits the use of lock-in detection without, as in the alternative Stark modulation method, disturbing the positions of the spectral lines.

The d-c Stark voltage, derived from a stack of radio B batteries, is connected through rf interference filters directly to the folded quarter-wave lines at one end of the resonator. The filters are necessary to keep out UHF emissions from nearby trucks and taxicabs, to which the maser receiver is very sensitive. By means of a calibrated volt box and precision potentiometer, the Stark voltage can be measured to an accuracy of $\pm 2$ parts in $10^5$.

## 3. Zero-Field Spectrum of HCN

The lowest excited vibration-rotation level of HCN, a bending level with vibrational quantum number $v_2 = 1$ and angular momentum quantum number $J = 1$, lies 712 $cm^{-1}$ above the ground state. Its fractional population is about $7 \times 10^{-4}$ which, while not large, is enough to yield a fairly intense radio spectrum. Centered at 449 MHz, this spectrum consists of the several hyperfine structure components of a single transition, the $\Delta J = 0$ transition between the two $l$-type doubling sublevels of the $J = 1$ level. The frequency of this transition, considering its hyperfine structure to be condensed to zero, is the "$l$-type doubling frequency," $\nu_l$, an accurate value of which is required for later analysis of the Stark effect. The following computation of hyperfine structure permits $\nu_l$ to be determined within $\pm 1$ part in $10^6$ from measurements on the 449 MHz spectrum.

### 3.1. Wavefunctions

The $v_2 = 1$ bending vibration of HCN is very nearly a conical pendulum motion of the hydrogen nucleus

[2] This item of commercial apparatus is identified solely to specify the experimental method, and is not thereby endorsed by the U.S. Government. A list of manufacturers and model numbers of other equipment is available on request to the author.

about the C–N axis. The two possible directions of rotation are represented by the functions $\psi(l)$ and $\psi(-l)$, where $l\hbar$ is the angular momentum of the rotary vibration projected along the symmetry axis of the molecule. When the molecule is at the same time rotating in its normal end-over-end way, the vibrational angular momentum vector becomes twisted slightly away from the symmetry axis, and this interaction between vibration and rotation causes an "$l$-type" doubling of every energy level in the vibrational state. A quantum mechanical analysis [12] shows that for a state with $v_2=1$ the energy separation of the two members of a doublet is ${}_qJ(J+1)$, where $J$ is the quantum number of resultant angular momentum, vibrational plus rotational. The factor $q$ depends on various constants of the molecule and on the energy separations of the different vibrational states that are admixed by the vibration-rotation perturbation. To account for this admixture, the wavefunctions of the doublet rotational levels in the lowest bending state of HCN can be written as:

$$\Pi_{\bar{J}} = 2^{-1/2}[\psi_J(l=1) - \psi_J(l=-1)], \tag{1a}$$

$$\Pi_{\dot{J}} = [2+\alpha^2]^{-1/2}[\psi_J(l=1) + \psi_J(l=-1)] + \alpha\psi_J(l=0) \tag{1b}$$

The bracketed sum-and-difference functions are the usual first order wave functions for degenerate levels. The selection rules for vibration-rotation perturbations permit only levels of the same parity, the same total angular momentum, and with $l$-values differing at most by 1 to be affected. Thus a $\Pi^-$ level can be perturbed by certain levels of $\Sigma^-(l=0)$ and $\Delta^-(l=2)$ vibrational states and a $\Pi^+$ level can be perturbed by certain levels of $\Sigma^+$ and $\Delta^+$ vibrational states [13]. Since HCN has no known $\Sigma^-$ states, and the $\Delta$ states are few and far removed in energy, the chief effect of the perturbation is felt by the $\Pi^+$ level: it acquires a small $l=0$ character and is shifted in energy. This neglect of perturbations by $\Delta$ states is perfectly justified for the $J=1$ level, the level of main interest here, because $\Delta$ states have no $J=1$ levels that can perturb it.

As can be demonstrated by applying the operator $J_x$ to (1b), a molecule in one of the $\Pi^+$ levels will have a component of vibrational angular momentum perpendicular to the symmetry axis, of magnitude proportional to the admixture coefficient, $\alpha$. This can have an effect on the hyperfine structure and Stark effect, and so it is necessary to know the size of $\alpha$. Perturbation theory gives an immediate rough estimate: $\alpha \simeq [qJ(J+1)/\omega_2]^{1/2}$ where $\omega_2$ is the bending frequency, and for $J=1$, this is $\alpha \simeq 5\times10^{-3}$. At the accuracy level of the present experiment, a better value of $\alpha$, which could be computed from the $l$-type doubling theory, is not needed.

### 3.2. Hyperfine Structure

Except for complications caused by vibration, HCN is a standard case [14] of hyperfine structure due to two nuclei, only one of which has an electric quadrupole moment. The hyperfine structure Hamiltonian is

$$H = H_Q + C_1\mathbf{I}_1\cdot\mathbf{J} + C_2\mathbf{I}_2\cdot\mathbf{J} \tag{2}$$

where $H_Q$ is the electric quadrupole interaction of the nitrogen nucleus with the molecular charge distribution, and the remaining two terms represent the magnetic coupling of the nitrogen and hydrogen nuclei with the molecular currents. The coupling constants depend on $J$ and $l$, and are discussed in detail by Tomasevitch and Klemperer [6]. The magnetic dipole interaction between the two nuclei is negligible because of their large separation. Because the nitrogen nuclear spin $\mathbf{I}_1$ is tightly coupled to the molecular angular momentum $\mathbf{J}$, but the hydrogen nuclear spin $\mathbf{I}_2$ is not, the hyperfine structure is best calculated with the $F_1$, $F$ coupling scheme, i.e., considering $\mathbf{F}_1=\mathbf{I}_1+\mathbf{J}$ as well as $\mathbf{F}=\mathbf{F}_1+\mathbf{I}_2$ to be constants of the motion. For the present case, the quantum number $F$ takes on the values $|F_1 \pm \tfrac{1}{2}|$, where $F_1=0,1,2$. The corresponding hyperfine structure sublevels of the two $l$-type doubling levels are shown by figure 2, which also indicates the various hyperfine structure components of the 449 MHz transition.

The effects of vibration on the hyperfine structure are large enough to be detectable only in the electric quadrupole interaction. They show up in the form of matrix elements of $H_Q$ which are off-diagonal in the quantum number $l$. Using the expanded form of the quadrupole operator given by Frosch and Foley [15] we find, by matrix multiplication, these matrix elements to be:

$$(l\ I_1JF_1|H_Q|l\pm1\ I_1JF_1) = eQq_1(2l\pm1)[J(J+1) - l(l\pm1)]^{1/2} \times f(I_1JF_1)/J(J+1), \tag{3}$$

and for $|l|=1$, the only important case,

$$(l\ I_1JF_1|H_Q|l\pm2\ I_1JF_1) = eQq_2f(I_1JF_1)/2. \tag{4}$$

As is customary, $Q$ represents the quadrupole moment of the nucleus and $f(I_1JF_1)$ represents Casimir's function of the quantum numbers $I_1$, $J$, and $F_1$, as defined by Bardeen and Townes [16]. The small $q$'s measure the distortion of the molecular electric field caused by vibration: $q_2$ measures a departure from azimuthal isotropy in the field gradient and $q_1$ measures a divergence of the principle axes of the field distribution from the principle axes of the nuclear framework. Departures from azimuthal isotropy are characteristic of asymmetric top molecules, for which they are commonly specified by a dimensionless parameter $\eta$. The relationship between $\eta$ and $q_2$ is $\eta=q_2/q$, where $q$ is the electric field gradient, at the quadrupolar nucleus, in the direction of the symmetry axis of the nuclear framework. Effects due to $q_1$ are too small to be concerned with except in rare cases, one of which is the strong-field correction mentioned in section 6.

The matrix element of $H_Q$ diagonal in $l$ is

$$(l\ I_1JF_1|H_Q|l\ I_1JF_1) = eQq[3l^2-J(J+1)]f(I_1JF_1)/J(J+1). \quad (5)$$

Combined with (3) and (4), this yields for the expectation value of the electric quadrupole interaction, evaluated with the functions (1a, 1b),

$$W_Q = eQq\left[\frac{3-J(J+1)}{J(J+1)} \pm \frac{\eta}{2}\right]f(I_1JF_1), \quad (6)$$

where the $\pm$ sign corresponds to the choice of functions $\Pi_J^+$ or $\Pi_J^-$. There is no dependence on $q_1$ because when $|l|=1$ the two cross product terms in the expectation value have opposite signs, and they cancel. This energy formula is identical with that for a slightly asymmetric top molecule in its $|K|=1$ level. It could have been written down immediately by exploiting the well-known similarity between bending linear molecules and asymmetric tops, and this was in fact done by White [17] in his analysis of the microwave $l$-type doubling spectra of HCN. The present approach, although more tedious, emphasizes that the sign choice in (6) refers not directly to the upper and lower energy levels of the $l$-type doublet, but rather refers to the symmetry of the two corresponding wavefunctions. If, as seems likely from the positions of perturbing levels, the $\Pi_J^+$ level is displaced downward in energy by the vibration-rotation interaction, then the upper sign in (6) must be used for the lower level, and vice versa. This assignment is opposite to that used by White, and has implications which are discussed below.

The magnetic hyperfine structure energies, computed from the vector model of angular momentum, are

$$W_M = \tfrac{1}{2}C_1[F_1(F_1+1)-J(J+1)-I(I+1)] + C_2[4F_1(F_1+1)]^{-1}[F_1(F_1+1)+J(J+1) -I_1(I_1+1)][F(F+1)-F_1(F_1+1) -I_2(I_2+1)], \quad (7)$$

and the complete hyperfine structure energy formula is the sum of (6) and (7).

## 4. Zero-Field Observations and Results

For measurements on the 449 MHz zero-field spectrum, a movable shorting plunger was used to tune a resonator similar to that of figure 1 to the frequencies of the several hyperfine structure components. Except for the $(F_1=0\rightarrow F_1=1)$ transitions, which were undetectable, all of the allowed transitions indicated in figure 2 were observed. The averaged results of three measurements of each line center are given in table 1. The line intensities were approximately proportional to the theoretical transition probabilities, and the signal-to-noise ratios ranged from 2 for the weakest $\Delta F \neq \Delta F_1$ line to 60 for the strongest $\Delta F=\Delta F_1=0$ line. Line widths were 3 kHz and except for the $\Delta F=\Delta F_1=0$ lines, which are superposed pairs, every line was completely resolved. The absence of the $(F_1=0\rightarrow F_1=1)$ lines is understandable from the fact that the upper $F_1=0$ levels transform into $m_J=0$ levels in the strong electric field of the state selector. Lacking a Stark effect, molecules in these levels are not state-selected, and a maser spectrometer cannot detect them. In a similar way it is possible to account for the somewhat higher intensity of the $(F_1=1\rightarrow F_1=2)$ lines relative to the $(F_1=2\rightarrow F_1=1)$ lines. The upper $F_1=1$ levels transform wholly into $m_J=\pm 1$ levels, with strong Stark effects, in the state selector, while the upper $F_1=2$ levels do not.

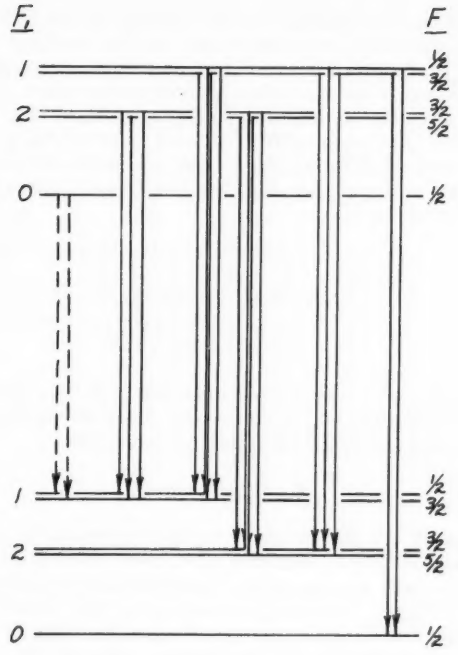


FIGURE 2. *Hyperfine structure components of the 449 MHz l-type doubling transition in HCN.*

Dashed lines represent components undetectable in the beam maser.

In fitting the energy formulas of the preceding section to the frequencies of table 1, corrections were made for the slight nonconstancy of $\mathbf{F}_1$ due to the magnetic $\mathbf{I}_2\cdot\mathbf{J}$ interaction, the necessary matrix elements being taken from Bardeen and Townes' paper [16]. The largest such correction was 0.3 kHz. To test for the presence of a magnetic dipole interaction between the nitrogen and hydrogen nuclei, two successive analyses of the data were made, the first with dipole interaction terms [18] added to the energy formula and the second with them omitted. The first analysis yielded dipole interaction constants a fraction of a kilohertz in magnitude, which is comparable with the measurement uncertainties. The second analysis showed, however, that the assumption of no dipole interaction gave an equally good fit to the data, and that therefore this interaction can be ignored at the present level of precision. The quality of fit was deter-



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mined by recomputing the frequencies of the 14 lines, using the constants determined in the analysis, and then evaluating the rms frequency error, weighted according to line intensity. This rms error was 0.3 kHz with the dipole interaction included, and 0.4 kHz without. The molecular constants determined in the two analyses differed slightly, but well within the experimental uncertainties, and the final results given here are the mean values.

$$\begin{aligned} \nu_l &= 448943.1 \pm 0.4 \text{ kHz} \\ eQq &= -4809.2 \pm 1.1 \text{ kHz} \\ |eQq\eta| &= 392.2 \pm 1.6 \text{ kHz} \\ C_1 &= 12.2 \pm 0.2 \text{ kHz} \\ C_2 &= -27.3 \pm 1.6 \text{ kHz} \end{aligned}$$

In each result, the quoted uncertainty is the variation of the constant which shifts one of the strong lines of the spectrum by 0.4 kHz, the rms fitting error.

## 5. Discussion

Except for the proton coupling constant, $C_2$, all of these molecular constants have been measured previously, with less precision, by absorption spectroscopy on HCN gas. Yarmus [5] observed a single broad line for the $J=1$ level, corresponding to the eight $\Delta F_1 = 0$ transitions of table 1. His derived value of the $l$-type doubling frequency, $448947 \pm 10$ kHz, agrees within 4 kHz with the present value of $\nu_l$. The doubling frequency may also be predicted from measurements on higher rotational levels: based on the recent work of Maki and Lide [19] this predicted value is $448943 \pm 1$ kHz, in near-perfect agreement with the present value. Within their experimental uncertainties, the values of $eQq$ and $C_1$ derived by Yarmus and the magnitude of $eQq\eta$ derived by White [17] from absorption measurements on higher rotational levels also agree with the present more precise values. The sign of $\eta$ cannot be determined from either the maser spectrum or the gas absorption spectrum without further information about which of the two levels, $\Pi_J^+$ or $\Pi_J^-$ of eq (1), is the upper level of each doublet. If $\Pi_J^+$ is the upper level, as assumed by White, then the disposition of lines in the observed spectrum requires $\eta$ to be negative; if $\Pi_J^+$ is the lower level, as suggested in section 3.2, then $\eta$ must be positive. This is not a trivial matter, since of the possible sources of electrical asymmetry in HCN some yield positive values of $\eta$ and some yield negative values [17]. Knowledge of the actual sign of $\eta$ can be used to eliminate some of these possibilities.

From unpublished information kindly given us by G. Tomasevitch, it appears that the Harvard and NBS measurements of the 449 MHz spectrum, made independently but by similar methods, disagree uniformly by about 1 kHz on each spectral line position, the Harvard measurements being higher. Consequently, the two values of the $l$-type doubling frequency differ by 1 kHz, as compared to 0.8 kHz allowed by the combined experimental uncertainties. The hyperfine structure constants, which are determined from line spacings within the spectrum and are hence free of the 1 kHz discrepancy, are in excellent agreement.

TABLE 1. *Zero-field UHF spectrum of the* $v_2=1$ J=1 *level of HCN*

The line frequencies are averages of three measurements and have an estimated uncertainty of 3 kHz divided by the relative intensity.

| $F_1 \rightarrow F_1'$ | $F \rightarrow F'$ | $\nu$(kHz) | Observed rel. intensity |
|---|---|---|---|
| 1→0 | 1/2→1/2 | 450821.1 | 6 |
| | 3/2→1/2 | 450801.7 | 10 |
| 1→2 | 3/2→5/2 | 449608.2 | 16 |
| | 1/2→3/2 | 449593.8 | 8 |
| | 3/2→3/2 | 449573.6 | 2 |
| 2→2 | 3/2→5/2 | 448996.3 | 2 |
| | [5/2→5/2 | 448962.7 | 32 |
| | 3/2→3/2] | | |
| | 5/2→3/2 | 448928.9 | 2 |
| 1→1 | 1/2→3/2 | 448864.3 | 2 |
| | [3/2→3/2 | 448844.9 | 8 |
| | 1/2→1/2] | | |
| | 3/2→1/2 | 448825.0 | 2 |
| 2→1 | 3/2→3/2 | 448233.3 | 1 |
| | 3/2→1/2 | 448213.1 | 6 |
| | 5/2→3/2 | 448199.6 | 10 |
| 0→1 | 1/2→1/2 | Not state-selected. | |
| | 1/2→3/2 | | |

## 6. Electric Resonance Spectrum of HCN

The Stark effect is large in HCN, due jointly to its dipole moment of nearly 3 D and the close spacing of its $l$-type doubling levels. A field strength of 100 V/cm shifts the 449 MHz spectrum upward in frequency to 475 MHz, and this was chosen as the operating point for electric resonance measurements. The spectrum, shown in figure 3, consists of four lines: a central pair and two weaker lines displaced by about 3 V/cm to higher and lower field strength. The central lines have widths of 30 mV/cm and the outer lines appear to be as broad, although their reduced intensity makes measurements difficult.

### 6.1. Stark Effect

At a field strength of 100 V/cm the nuclear spins of both the hydrogen and the nitrogen nuclei are decoupled from the molecular angular momenta, and the Stark shifts of energy levels are practically independent of hyperfine structure. For purposes of analysis, this means that the Stark effect can be computed first to the necessary precision, and then corrected for hyperfine structure by standard perturbation theory.

Because rotational energy level separations are large in HCN, the Stark effect is given by the standard formula for an isolated pair of interacting levels, with original energies $W_1^\circ$ and $W_2^\circ$ [20],

$$W_{\text{Stark}} = \tfrac{1}{2}(W_1^\circ + W_2^\circ) \pm \tfrac{1}{2}[(W_1^\circ - W_2^\circ)^2 + 4W_{12}^2]^{1/2}, \quad (8)$$

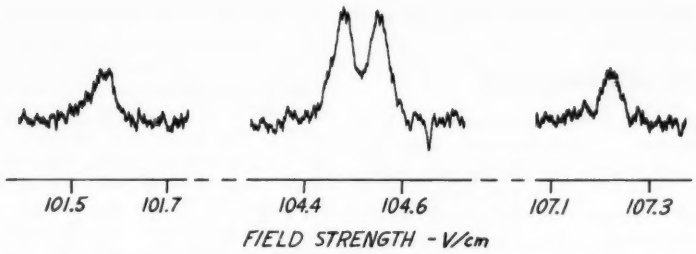


FIGURE 3. *Electric resonance spectrum of HCN at a fixed frequency of 474.898 MHz.*

The d-c electric field is parallel to the rf electric field.

where in this case $W_1^\circ - W_2^\circ = qJ(J+1)$, the $l$-type doubling interval, and $W_{12}$, the matrix element of the interaction, is the Stark matrix element $(\Pi_J^- | \boldsymbol{\mu}\cdot\mathbf{E} | \Pi_J^+)$. From the vector model of angular momentum, $\boldsymbol{\mu}\cdot\mathbf{E}$ may be rewritten as

$$\boldsymbol{\mu}\cdot\mathbf{E} = (\boldsymbol{\mu}\cdot\mathbf{J})(\mathbf{J}\cdot\mathbf{E})/J^2 = (\boldsymbol{\mu}\cdot\mathbf{J})m_J E/J(J+1), \quad (9)$$

which is useful for computing matrix elements diagonal in $J$. The quantity $(\boldsymbol{\mu}\cdot\mathbf{J})$, a scalar, may be evaluated in any coordinate system, but most easily in a coordinate system attached to the molecule, in which $J_z = l$. Thus

$$\boldsymbol{\mu}\cdot\mathbf{J} = \mu_z l + \mu_x J_x + \mu_y J_y. \quad (10)$$

In a linear molecule, such as HCN in its ground state, perpendicular components of the permanent dipole moment must vanish because of symmetry ($\mu_x = \mu_y = 0$). This is not necessarily true for the bending vibrational state, but any perpendicular component will certainly be very small, and will be neglected temporarily. The Stark matrix element, evaluated with the functions (1a) and (1b), is then

$$W_{12} = (\Pi_J^- | \boldsymbol{\mu}\cdot\mathbf{E} | \Pi_J^+) = |l| m_J \mu E/J(J+1), \quad (11)$$

where $\mu$ has been written for $\mu_z(1+\alpha^2/2)^{-1/2}$, and represents the experimentally determined dipole moment. Since $\alpha$ has the approximate value $2\times10^{-3}J(J+1)$, the $J$-dependence of the dipole moment from this source is negligible for low $J$ values.

### 6.2. Strong Field Hyperfine Structure

The Stark effect depends only on the absolute value of the quantum number $m_J$, and so it leaves a twofold degeneracy of the sublevels labeled by $+m_J$ and $-m_J$. Since the electric quadrupole interaction couples sublevels with the same value of $m_J + m_1$, this means that a quadratic secular equation must be solved for the hyperfine structure of the sublevels $m_J, m_1 = \pm 1, \mp 1$. The procedure is similar to that used by Bhattacharya and Gordy [21] for the ground vibrational state of HCN, but with the effects of vibrational angular momentum included. For the present case, with $I = J = l = 1$, the results are

for $m_J = 0$:

$$W_{hfs} = -eQq|1\pm\eta)(3m_1^2-2)/20, \quad (12)$$

for $|m_J| = 1$, $m_J + m_1 \neq 0$:

$$W_{hfs} = eQq(1\pm\eta)(3m_1^2-2)/40 + C_1 m_1 m_J + C_2 m_2 m_J,$$

for $|m_J| = 1$, $m_J + m_1 = 0$:

$$W_{hfs} = eQq(1\pm\eta)/40 - C_1[\pm][(m_2 C_2)^2 + (3eQq/20)^2(1\pm\eta)^2]^{1/2}.$$

The sign choice $\pm$ again refers to the two $l$-type doublet levels, but $[\pm]$ refers to the two $|m_J| = 1$ sublevels, formerly degenerate, that are now separated by the electric quardupole interaction.

## 7. Corrections

The perturbation calculation of energies can be carried to second order to evaluate certain small corrections and to show that others are negligible.

a. *Intermediate field effects.*—The quadrupole interaction couples the sublevels $m_J = 0$ and $|m_J| = 1$, and causes energy shifts of order $(W_Q)^2/W_{Stark}$. These shifts are comparable with the line width, and were computed and applied to each line of the electric resonance spectrum. Similar effects in the magnetic hyperfine structure are negligible.

b. *Rotational Stark Effect.*—The normal second-order Stark effect of linear molecules, of order $(\mu E)^2/W_{rot}$, also causes level shifts comparable with the line width, but it affects both components of the $l$-type doublet equally, or very nearly so. The effect on the electric resonance spectrum is negligible.

c. *Field-induced electric quadrupole interactions.*—Strong fields mix the $l$-type doublet wavefunctions (1) and destroy the strict cancellation of certain quadrupole matrix elements. One such field-induced interaction is that involving $\Delta l = 2$ matrix elements across the $l$-type doublet, of order $W_Q^2 W_{Stark}/(h\nu_l)^2$. Another is that involving $\Delta l = 1$ matrix elements within each component of the $l$-type doublet, of order $W_Q[W_{Stark}/W_{vib}]^{1/2}$. At a field strength of 100 V/cm both cause level shifts of less than one tenth of the observed line width. This is negligible, but barely so. Reduced line

widths or stronger fields would require corrections to be made for these interactions.

## 8. Results and Discussion

The matter of line widths is of first importance in a precision electric resonance spectrometer, and the observed width of 30 mV/cm is disappointingly large. The expected width, based on the quadratic Stark effect, is $\Delta E = \Delta\nu/2kE$, where $k$ is the Stark coefficient and has the approximate value 2.5 kHz/(V/cm)$^2$. For $\Delta\nu = 3$ kHz, the measured frequency width at zero field, this predicts a width of 6 mV/cm, some five times smaller than the observed width, at a field strength of 100 V/cm. Two possible sources of the excess width are nonuniformity of the Stark field (although the field was expected to be much better than this) and unresolved structure in the lines.

There is some evidence on the question of field uniformity, in the form of resonance spectra observed with a Stark cell of much poorer quality. This cell was made from steel plates 6 mm thick, surface-ground in an instrument shop and then electroplated with silver. The plates showed a warpage, when placed together, of about 1/10 mm, and had to be clamped across their quartz spacers in order to get contact with all four spacers. Line widths observed with this Stark cell, at the same field strength, were also 30 mV/cm. This observation does not rule out all broadening due to field nonuniformity, for the overall geometry of the two cells was similar and the fringing fields at the beam entrance holes, for example, should be much the same. Tests were made with a mica beam stop to investigate the effects of fringing fields, but the beam stop reduced the signal intensity so much that the results were inconclusive.

Unresolved structure could be present in the two central lines of the electric resonance spectrum, which are actually superposed line pairs because of the $\pm m_J$ degeneracy. The quadrupole interaction does not split these line pairs as it does the two outlying lines of the spectrum, but a small linear Stark effect, sensitive to the sign of $m_J$ as well as its absolute value, would do so. Such a linear Stark effect would result from a component of the electric dipole moment perpendicular to the molecular axis. The necessary size of this dipole moment can be calculated with the Stark effect operator (10) and the wavefunctions (1), and turns out to be approximately $10^{-2}$ D for a line splitting of 20 mV/cm. Gyroscopic distortion effects in a bending linear rotor might generate a perpendicular moment of this size, but it is somewhat doubtful. Experimental verification can be sought by comparing the widths of the central lines of the spectrum with the widths of the outlying lines. Since it is apparent from the spectrum of figure 3 that the outlying lines are not greatly narrower than the central lines, we conclude that unresolved structure is not an important source of excess line width, and that a perpendicular component of the dipole moment, if any exists, is less than $10^{-3}$ D in size.

The center lines of the electric resonance spectrum were measured repeatedly over a period of several days to check the stability of the maser spectrometer. The minute-to-minute voltage readings of the line centers, at constant frequency, did not differ by more than 2 or 3 parts in $10^5$, which is consistent with the line width of 3 parts in $10^4$ and the signal-to-noise ratio of 8/1. The long-term stability was found, however, to be considerably worse. Measurements made a few days apart differed by as much as 4 parts in $10^4$, and on a weekly basis there was a comparable net drift toward higher voltages. We have not made a thorough study of these instabilities, and do not know their cause, although certain sources of trouble can be ruled out. Instabilities in the frequency and voltage measuring apparatus are in the part-per-million range or smaller, and so cannot contribute. Thermal effects, in our air-conditioned laboratory, should be no larger. The observed monotonic drift is suggestive of a gradual change in the chemical or mechanical properties of the Stark cell, such as a relaxation of strain in the aluminum plates or their mounting, or the buildup of a dielectric film on the plate surfaces. Aluminized glass Stark cells have proved troublesome in other laboratories, presumably due to oxidation since a gold flash coating removes the difficulty. Oil migration from the diffusion pump is a distinct possibility, and could be checked by replacing the present room-temperature chevron baffle with a cooled baffle. We note finally, that a non-uniform dielectric film buildup could account for both the long-term instabilities and the excess line widths. It is, in our opinion, the most likely source of imprecision in the present spectrometer.

A value of the HCN electric dipole moment may be derived by fitting eqs (8), (11), and (12) to the electric resonance spectrum, including the corrections of section 7. The result is

$$\mu = 2.940 \pm 0.001 \text{ D}.$$

This is based on measurements made near the start of the stability tests, but the assigned uncertainty is large enough to include all later measurements as well. This figure agrees, within experimental errors, with Tomasevitch and Klemperer's [6] value $2.9416 \pm 0.0016$ D.

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# The Second Spectrum of Nickel (Ni II)

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An analysis of Ni II based on 4300 observed lines is presented. The low structures are $3d^9$, $3d^8\,4s$ and $3d^7\,4s^2$ which are now complete except for $3d^8(^1S)4s\ ^2S$ and $3d^7\,4s^2\ ^2P_{1/2}$ and the higher of the two $^2D$ terms of $3d^7\,4s^2$. Long series occur such as $3d^8\,4s$ to $9s$, $4d$ to $8d$, $4f$ to $7f$, $5g$ to $7g$. The analysis also includes many terms of the complex structure $3d^7\,4s\,4p$ but only 55 percent of the levels within reach of the hollow cathode source have been found. The identification of the levels of $3d^8\,4d$ and $5d$ was assisted by the calculations of N. Spector. The $4d^7\,4s^2$ levels were calculated by Y. Shadmi, who also provided calculated positions for all the levels of $3d^7\,4s\,4p$ without which much of the analysis would have been impossible. The $3d^8\,ns$ and $3d^8\,nd$ series give a limit of 146532.0 but the $3d^8\,ng$ series gives 146541.56. The latter has been adopted though no explanation of the discrepancy has been found.

Key words: Energy levels; ionization potential; nickel; spectral series; spectroscopy; wavelength.

## 1. Introduction

Although there can be no such thing as a complete analysis of an atomic spectrum, there is no doubt that, by any criterion, many of the analyses published during the 1920's were quite inadequate. There were even some which were completely false. This situation was in part due to the paucity of available spectrum sources. First spectra could be fairly well analyzed from observations made with ordinary arcs in air or a partial vacuum. For second spectra one had to rely on more energetic sources such as the condensed spark under various electrical conditions. Such sparks do not in general give sharp lines or any lines due to high energy levels. Under those conditions I analyzed three second spectra in the 1920's, namely Cu II, Ni II, Pd II [1][1] but I was able to observe only the lowest levels and one higher term which provided the means for calculating the ionization potential to a first approximation. Higher ionizations required still more energetic sources and the very high ionizations had to wait for the full development of the spark in vacuo.

With the invention or discovery of the hollow cathode discharge by Paschen and its development by many physicists for a great variety of purposes, a remarkable source of second spectra became available. It has the ability to produce sharp lines even from high levels and to excite those levels strongly by collisions of the second kind between the atoms of the carrying gas and the atoms of the element composing part or all of the hollow cathode. The excitation is usually limited by the ionization potential of the carrying gas and helium is therefore the gas which gives the highest excitation. Its ionization potential is unfortunately a little small to carry most metals up to double ionization, which corresponds to the limit of the second spectrum.

After the second World War, I devoted my time mainly to the analysis of third spectra, one of which was Cu III for which a sliding spark or pulsed hollow-cathode was reasonably adequate. Difficulties with that spectrum led me to turn to the isoelectronic spectrum, Ni II, for help. The elements iron, cobalt, and nickel had proved in the past very difficult to excite in a hollow cathode [2] but with the high power that I had available from a constant current circuit, I decided to try the effect of going to high currents and temperatures. The result was startling and somewhat disconcerting, because the number of lines observed with this source reached 4500 in place of the few hundred with which I had worked in the 1920's. This great increase in available data made it evident that a new analysis of Ni II should be made and I therefore undertook it with some reluctance. The analysis of Cu III has, consequently, been in abeyance awaiting the extended analysis of Ni II.

## 2. Instruments and Observations

The whole spectrum was photographed in this laboratory with the following instruments.

1. A normal incidence vacuum spectrograph employing a grating of 30,000 lines per inch ruled by R. W. Wood on glass. It has no metallic surface but glass is nearly as good as any metal in the short wavelength region. This instrument gives beautiful spectra from

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[1] Figures in brackets indicate the literature references at the end of this paper.

2000 to 500 Å on a 16-inch plate, the resolving power being limited by the grain of the Ilford Q2 plates used.

2. A 21-foot Paschen circular spectrograph employing a Bausch and Lomb 30,000 lines per inch replica grating, the original of which was ruled for me. Unfortunately it shows a close satellite which can be only partially eliminated at the expense of reducing the area to 4 inch × 1 inch. The spectra from 2000 to 6500 Å were taken on this instrument, with suitable Eastman plates.

3. A Wadsworth spectrograph using a grating of 21-foot radius and 15,000 lines per inch. The grating was ruled by Professor Strong at Johns Hopkins on his new engine. It is blazed at about 9000 Å in the first order. The spectra from 6000 to 11,000 Å were taken on this instrument.

4. The Bureau of Standards 30,000 lines per inch, 10 meter vacuum instrument was used by Dr. Kaufman to photograph the spectrum form 500 to 2223 Å for me. He used a water-cooled hollow cathode source and obtained spectra with nearly all the lines I found on my smaller instrument. The plates were measured by C. H. Corliss and some parts later by myself. The importance of these observations can hardly be exaggerated. In particular the high dispersion allowed a differentiation of line widths which led to the discovery that about 130 lines were due to the hydrogen molecule. Those lines appeared slightly broadened and a large number of them could be identified from a paper by C. Rulon Jeppesen [3]. There is however, another group from 1623 to 1555 Å which is not included in Jeppesen's paper. The presence of hydrogen bands on the plates taken with the vacuum instruments is due to the difficulty of cleaning the discharge tube after exposure to air while being attached to the spectrograph. On the other hand, the amount of hydrogen present in the sealed off tube is extremely small.

All of the plates from my instruments were measured by me on either or both of two comparators in this laboratory. One is a Hilger instrument of high accuracy and the other a Societe Genevoise comparator of 40-cm travel but having an accuracy of only about ±0.002 mm. The standards in the region below 2100 Å were from a minute amount of copper in the cathode and from the usual impurities such as carbon and nitrogen. In the region from 2000 to 7000 Å the lines of Ni I and II [4] measured interferometrically by Burns were used wherever possible. They were usually immensely overexposed but a very short exposure put on after moving the occultor about a millimeter could be used with some confidence. In the red and infrared, neon lines from a slight impurity were very useful.

The accuracy of measurement throughout the whole spectrum is not as great as I had hoped, but the effort of remeasurement is too great for me to undertake after the several years I have spent on the analysis. The fault in the 21 foot grating is certainly partly responsible for the inaccuracies.

## 3. Sources

Although the chief source for the Ni II spectrum was the hollow cathode tube, both arc and spark spectra had to be taken in order to eliminate new arc lines. The electrodes for all sources were made of the purest nickel available (99.95%).

A plate of the arc in nitrogen was taken on the vacuum spectrograph and many arc lines were observed for the first time. Their measurement not only allowed me to eliminate arc lines from my lists in the Schumann region but they were also of great assistance to Miss Weeks of the Harvard Observatory in the calculation of wavelengths in absorption spectra taken at the Argonne Laboratory.

The hollow cathode tube was a two liter Pyrex flask fitted with ground glass joints for the anode, cathode and observation end. The last could be fitted directly on to the slit tube of the vacuum instrument or it could be closed by a short extension carrying a quartz window. The tube was mounted on a moveable gas circulation system which included a mercury circulation pump, a gas dosing tube and suitable traps cooled by liquid nitrogen. The hollow cathode was of about 1 cm internal diameter and 3 cm long, and was suspended from nickel rods by nickel wires. The anode was a disk of graphite. Before the system was cutoff from the high vacuum pumps the discharge was run for hours and even days and refilled with fresh helium until the spectrum appeared to be free from every impurity except small traces of mercury and hydrogen. The tube was operated at a helium pressure of 3 to 8 mm Hg at a current which heated the cathode nearly white hot. This was always between 0.5 and 1.5 A with a voltage of 250 to 600. With time the voltage rose slowly and the current had to be cut down to prevent melting, which occasionally occurred in spite of all precautions.

Two constant current circuits were available, the first being a 2-phase monocyclic network like the 3-phase circuit described by Green and Kuper [5]. The second was designed and built here by James Brault. It employs Sola transformers and transistor rectifiers and operates on 3-phase.

The exposures were made long enough to register lines of intrinsically low intensity. This necessitated times of 20 minutes to 2 hours with resultant immense over-exposure of all the strong lines. The device mentioned above of putting tails of very short exposure on all the strong lines made possible the measurement of a great range of intensities on any plate. In some ranges shorter exposures were made for special purposes. The relative intensities of many of the lines were estimated from plates taken with successive exposures of 1, 2, 4, 8, 16, 32, 64, 128 and 256 s. Table I is a list of the 4300 lines on which the analysis is based.

## 4. Analysis

I once made the remark in public that anyone working on the spectra of the atoms of the first or second *d*-periods without consulting the theoretical work of Racah and his school would be wasting valuable time. In the present case, I avoided much waste of time by consulting Y. Shadmi to obtain the most recent calculations of the low even levels of Ni II. He responded most generously by recalculating the even

## TABLE I. *Lines of* Ni II

| λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 727.100 | 2h | 137532.7 | $3d\,^2D_{2\frac{1}{2}} - 7f\,^4D^\circ_{2\frac{1}{2}}$? |
| 737.300 | 5 | 135630.0 | $3d\,^2D_{2\frac{1}{2}} - 6f\,^2F^\circ_{3\frac{1}{2}}$ |
| | | | $3d\,^2D_{2\frac{1}{2}} - 6f\,^2D^\circ_{2\frac{1}{2}}$ |
| 738.201 | 2 | 135464.5 | $3d\,^2D_{2\frac{1}{2}} - 4f''\,^2G^\circ_{3\frac{1}{2}}$ |
| 738.548 | 1 | 135400.8 | $3d\,^2D_{2\frac{1}{2}} - 4f''\,^2F^\circ_{3\frac{1}{2}}$ |
| 744.636 | 2 | 134293.8 | $3d\,^2D_{2\frac{1}{2}} - 6f\,^4D^\circ_{2\frac{1}{2}}$ |
| 744.867 | 5 | 134252.2 | $3d\,^2D_{2\frac{1}{2}} - 6f\,^4P^\circ_{1\frac{1}{2}}$ |
| | | | $3d\,^2D_{2\frac{1}{2}} - 6f\,^4S^\circ_{1\frac{1}{2}}$ |
| 745.640 | 1 | 134113.0 | $3d\,^2D_{1\frac{1}{2}} - 6f\,^4D^\circ_{1\frac{1}{2}}$ |
| 746.241 | 5 | 134005.0 | $3d\,^2D_{1\frac{1}{2}} - 4f''\,^4D^\circ_{2\frac{1}{2}}$ |
| 746.525 | 0 | 133954.0 | $3d\,^2D_{1\frac{1}{2}} - 4f''\,^4F^\circ_{2\frac{1}{2}}$ |
| 752.403 | 0 | 132907.5 | $3d\,^2D_{2\frac{1}{2}} - 4f'\,^2D^\circ_{2\frac{1}{2}}$? |
| 752.626 | 4 | 132868.1 | $3d\,^2D_{2\frac{1}{2}} - 4f'\,^2F^\circ_{3\frac{1}{2}}$ |
| 767.898 | 1 | 130225.6 | $3d\,^2D_{2\frac{1}{2}} - 5f\,^2F^\circ_{3\frac{1}{2}}$ |
| 771.626 | 1 | 129596.5 | $3d\,^2D_{1\frac{1}{2}} - 5f\,^4G^\circ_{2\frac{1}{2}}$ |
| 776.000 | 3 | 128866.0 | $3d\,^2D_{2\frac{1}{2}} - 5f\,^4F^\circ_{3\frac{1}{2}}$ |
| 776.078 | 5 | 128853.0 | $3d\,^2D_{2\frac{1}{2}} - 5f\,^4D^\circ_{2\frac{1}{2}}$ |
| 795.506 | 10 | 125706.15 | $4s\,^4F_{4\frac{1}{2}} - v\,^4G^\circ_{5\frac{1}{2}}$ |
| 797.074 | 200 | 125458.87 | $4s\,^4F_{4\frac{1}{2}} - v\,^4F^\circ_{4\frac{1}{2}}$ |
| 797.088 | 150 | 125456.66 | $4s\,^4F_{4\frac{1}{2}} - s\,^4D^\circ_{3\frac{1}{2}}$ |
| 798.518 | 30 | 125231.99 | $3d\,^2D_{1\frac{1}{2}} - x\,^4S^\circ_{1\frac{1}{2}}$ |
| | | | $4s\,^4F_{4\frac{1}{2}} - v\,^4G^\circ_{5\frac{1}{2}}$? |
| 799.145 | 2 | 125133.74 | $4s\,^4F_{3\frac{1}{2}} - v\,^4F^\circ_{3\frac{1}{2}}$ |
| 802.292 | 100 | 124642.90 | $4s\,^4F_{3\frac{1}{2}} - s\,^4D^\circ_{2\frac{1}{2}}$ |
| 803.064 | 15 | 124523.08 | $4s\,^4F_{3\frac{1}{2}} - v\,^4F^\circ_{4\frac{1}{2}}$ |
| 805.168 | 150 | 124197.68 | $4s\,^4F_{3\frac{1}{2}} - v\,^4F^\circ_{3\frac{1}{2}}$ |
| 806.188 | 30 | 124040.54 | $4s\,^4F_{2\frac{1}{2}} - s\,^4D^\circ_{1\frac{1}{2}}$ |
| 807.391 | 0 | 123855.73 | $4s\,^4F_{2\frac{1}{2}} - s\,^4D^\circ_{2\frac{1}{2}}$ |
| 808.933 | 5 | 123619.63 | $4s\,^4F_{1\frac{1}{2}} - s\,^4D^\circ_{0\frac{1}{2}}$ |
| 809.772 | 0 | 123491.55 | $4s\,^4F_{1\frac{1}{2}} - s\,^4D^\circ_{1\frac{1}{2}}$ |
| 810.292 | 20 | 123412.30 | $4s\,^4F_{2\frac{1}{2}} - v\,^4F^\circ_{3\frac{1}{2}}$ |
| 811.389 | 2 | 123245.45 | |
| 812.388 | 100 | 123093.89 | $4s\,^4F_{2\frac{1}{2}} - v\,^4F^\circ_{2\frac{1}{2}}$ |
| 813.602 | 2 | 122910.22 | |
| 814.050 | 5 | 122842.58 | $4s\,^2F_{3\frac{1}{2}} - 6p'\,^2F^\circ_{3\frac{1}{2}}$ |
| 815.570 | 5 | 122613.63 | $4s\,^4F_{2\frac{1}{2}} - 4f'\,^2F^\circ_{2\frac{1}{2}}$ |
| 816.024 | 8 | 122545.41 | $4s\,^4F_{1\frac{1}{2}} - v\,^4F^\circ_{2\frac{1}{2}}$ |
| 816.150 | 30 | 122526.50 | $4s\,^4F_{1\frac{1}{2}} - v\,^4F^\circ_{1\frac{1}{2}}$ |
| 816.156 | 150 | 122525.60 | $4s\,^2F_{3\frac{1}{2}} - v\,^2G^\circ_{4\frac{1}{2}}$ |
| 816.864 | 1 | 122419.40 | |
| 817.884 | 1 | 122266.73 | $4s\,^4F_{4\frac{1}{2}} - 7p\,^4G^\circ_{5\frac{1}{2}}$ |
| 819.090 | 5 | 122086.71 | $4s\,^4F_{4\frac{1}{2}} - 7p\,^4D^\circ_{3\frac{1}{2}}$ |
| 821.612 | 1 | 121711.95 | $4s\,^2F_{3\frac{1}{2}} - 8p\,^4G^\circ_{4\frac{1}{2}}$ |
| 821.634 | 20 | 121708.69 | $4s\,^2F_{3\frac{1}{2}} - v\,^2D^\circ_{2\frac{1}{2}}$ |
| 821.875 | 1 | 121673.00 | |
| 823.277 | 3 | 121465.80 | |
| 824.856 | 2 | 121233.28 | $4s\,^2F_{3\frac{1}{2}} - w\,^2D^\circ_{2\frac{1}{2}}$ |
| 828.152 | 10 | 120750.78 | $4s\,^2F_{2\frac{1}{2}} - 4f''\,^2G^\circ_{3\frac{1}{2}}$ |
| 828.786 | 1 | 120658.41 | $4s\,^2F_{3\frac{1}{2}} - w\,^2F^\circ_{2\frac{1}{2}}$ |
| 830.677 | 2 | 120383.73 | |
| 831.475 | 2 | 120268.20 | $3d\,^2D_{2\frac{1}{2}} - 4f\,^2F^\circ_{3\frac{1}{2}}$ |
| 834.059 | 100 | 119895.59 | $4s\,^2F_{3\frac{1}{2}} - w\,^2G^\circ_{4\frac{1}{2}}$ |
| 835.739 | 0 | 119654.58 | $3d\,^2D_{1\frac{1}{2}} - 4f\,^4F^\circ_{1\frac{1}{2}}$ |
| 835.983 | 75 | 119619.66 | $4s\,^2F_{3\frac{1}{2}} - w\,^2F^\circ_{3\frac{1}{2}}$ |
| 836.954 | 1 | 119480.88 | $4s\,^2F_{3\frac{1}{2}} - 4f'\,^2H^\circ_{4\frac{1}{2}}$ |
| 837.624 | 50 | 119385.31 | $4s\,^2F_{2\frac{1}{2}} - w\,^2G^\circ_{3\frac{1}{2}}$ |
| 838.224 | 10 | 119299.85 | $4s\,^2F_{2\frac{1}{2}} - 6f\,^4D^\circ_{2\frac{1}{2}}$ |
| 838.524 | 1 | 119257.17 | |
| 838.834 | 50 | 119213.10 | $4s\,^2F_{2\frac{1}{2}} - w\,^2F^\circ_{2\frac{1}{2}}$ |
| 840.878 | 5 | 118923.32 | $3d\,^2D_{2\frac{1}{2}} - 4f\,^4F^\circ_{3\frac{1}{2}}$ |
| 841.056 | 10 | 118898.15 | $3d\,^2D_{2\frac{1}{2}} - 4f\,^4D^\circ_{2\frac{1}{2}}$ |
| 841.205 | 0 | 118877.09 | $3d\,^2D_{2\frac{1}{2}} - 4f\,^4P^\circ_{1\frac{1}{2}}$ |
| 844.748 | 2 | 118378.50 | $3d\,^2D_{2\frac{1}{2}} - 5p'\,^2F^\circ_{2\frac{1}{2}}$ |
| | | | $4s\,^2F_{3\frac{1}{2}} - 7p\,^2G^\circ_{4\frac{1}{2}}$ |
| 845.033 | 3 | 118338.57 | |
| 849.086 | 5 | 117773.70 | |
| 849.398 | 5 | 117730.44 | |
| 854.604 | 3 | 117013.26 | |
| 855.282 | 5 | 116920.50 | $4s\,^2F_{3\frac{1}{2}} - 7p\,^4F^\circ_{4\frac{1}{2}}$ |
| 858.562 | 2 | 116473.83 | |
| 876.829 | 0 | 114047.32 | $4s\,^4F_{4\frac{1}{2}} - 6p\,^4F^\circ_{4\frac{1}{2}}$ |
| 881.608 | 2 | 113429.10 | $4s\,^4F_{4\frac{1}{2}} - 6p\,^4D^\circ_{3\frac{1}{2}}$ |
| 882.337 | 1 | 113335.38 | |
| 888.818 | 5 | 112508.97 | $4s\,^4F_{4\frac{1}{2}} - 5p''\,^4D^\circ_{3\frac{1}{2}}$ |
| 893.630 | 3 | 111903.14 | |
| 894.004 | 2 | 111856.32 | $4s'\,^2D_{2\frac{1}{2}} - w\,^2D^\circ_{1\frac{1}{2}}$ |
| 895.093 | 1 | 111720.23 | $4s\,^4F_{3\frac{1}{2}} - 5p''\,^4D^\circ_{2\frac{1}{2}}$ |
| 895.458 | 15 | 111674.70 | $4s'\,^2D_{2\frac{1}{2}} - w\,^2D^\circ_{2\frac{1}{2}}$ |
| 896.168 | 5 | 111586.22 | $4s'\,^2D_{1\frac{1}{2}} - w\,^2P^\circ_{1\frac{1}{2}}$ |
| 898.716 | 2 | 111269.86 | $4s\,^4F_{2\frac{1}{2}} - 5p''\,^4D^\circ_{1\frac{1}{2}}$ |
| 898.821 | 5 | 111256.86 | |
| 900.510 | 00 | 111048.18 | $4s'\,^2D_{2\frac{1}{2}} - s\,^4D^\circ_{1\frac{1}{2}}$ |
| 901.007 | 10 | 110986.93 | $4s'\,^2D_{1\frac{1}{2}} - w\,^2D^\circ_{2\frac{1}{2}}$ |
| 901.737 | 2 | 110897.08 | $4s\,^4F_{1\frac{1}{2}} - 5p''\,^4D^\circ_{0\frac{1}{2}}$ |
| 901.999 | 50 | 110864.87 | $4s'\,^2D_{2\frac{1}{2}} - s\,^4D^\circ_{2\frac{1}{2}}$ |
| 902.687 | 1 | 110780.37 | |
| 902.996 | 75? | 110742.46 | $4s'\,^2D_{2\frac{1}{2}} - s\,^4D^\circ_{3\frac{1}{2}}$ |
| 904.205 | 2 | 110594.39 | $4s''\,^4P_{1\frac{1}{2}} - w\,^2P^\circ_{1\frac{1}{2}}$ |
| 904.986 | 1 | 110498.95 | $4s\,^4F_{4\frac{1}{2}} - 4f\,^4H^\circ_{5\frac{1}{2}}$ |
| | | | $4s'\,^2D_{1\frac{1}{2}} - 6f\,^4D^\circ_{2\frac{1}{2}}$ |
| 905.634 | 100 | 110419.88 | $4s'\,^2D_{2\frac{1}{2}} - v\,^4F^\circ_{3\frac{1}{2}}$ |
| 905.696 | 3 | 110412.32 | $4s'\,^2D_{1\frac{1}{2}} - w\,^2F^\circ_{2\frac{1}{2}}$ |
| 906.123 | 15 | 110360.29 | $4s'\,^2D_{1\frac{1}{2}} - s\,^4D^\circ_{2\frac{1}{2}}$ |
| 906.237 | 2 | 110346.41 | $4s''\,^4P_{2\frac{1}{2}} - w\,^2P^\circ_{1\frac{1}{2}}$ |
| 906.730 | 1 | 110286.41 | |
| 906.906 | 1 | 110265.01 | |
| 907.630 | 50 | 110177.05 | $4s'\,^2D_{1\frac{1}{2}} - s\,^4D^\circ_{2\frac{1}{2}}$ |
| 907.692 | 10 | 110169.53 | $4s\,^4F_{4\frac{1}{2}} - 5p'\,^2F^\circ_{3\frac{1}{2}}$ |
| 908.258 | 40 | 110100.87 | $4s'\,^2D_{2\frac{1}{2}} - v\,^4F^\circ_{2\frac{1}{2}}$ |
| 908.584 | 20 | 110061.37 | $4s'\,^2D_{2\frac{1}{2}} - w\,^2F^\circ_{3\frac{1}{2}}$ |
| 909.683 | 10 | 109928.40 | $4s''\,^4P_{2\frac{1}{2}} - w\,^2D^\circ_{1\frac{1}{2}}$ |
| 911.187 | 15 | 109746.96 | $4s''\,^4P_{2\frac{1}{2}} - w\,^2D^\circ_{2\frac{1}{2}}$ |
| 913.187 | 2 | 109506.60 | $4s''\,^4P_{1\frac{1}{2}} - 6f\,^4D^\circ_{2\frac{1}{2}}$ |
| 913.279 | 3 | 109495.56 | $4s''\,^4P_{1\frac{1}{2}} - s\,^4D^\circ_{0\frac{1}{2}}$ |
| 913.678 | 75 | 109447.75 | $4s''\,^4P_{0\frac{1}{2}} - s\,^4D^\circ_{0\frac{1}{2}}$ |
| 913.909 | 15 | 109420.08 | $4s''\,^4P_{1\frac{1}{2}} - w\,^2F^\circ_{2\frac{1}{2}}$ |
| 914.343 | 50 | 109368.15 | $4s''\,^4P_{1\frac{1}{2}} - s\,^4D^\circ_{1\frac{1}{2}}$ |
| 914.743 | 40 | 109320.32 | $4s''\,^4P_{0\frac{1}{2}} - s\,^4D^\circ_{1\frac{1}{2}}$ |
| 915.471 | 1 | 109233.39 | $4s\,^4F_{3\frac{1}{2}} - 5p'\,^2F^\circ_{3\frac{1}{2}}$ |
| 915.877 | 75 | 109184.97 | $4s''\,^4P_{1\frac{1}{2}} - s\,^4D^\circ_{2\frac{1}{2}}$ |
| 915.920 | 30 | 109179.84 | $4s\,^4F_{4\frac{1}{2}} - w\,^4F^\circ_{4\frac{1}{2}}$ |
| 916.449 | 1 | 109116.82 | $4s'\,^2D_{2\frac{1}{2}} - v\,^4P^\circ_{1\frac{1}{2}}$ |
| 917.017 | 10 | 109049.23 | $4s\,^4F_{3\frac{1}{2}} - 5p'\,^2F^\circ_{2\frac{1}{2}}$ |
| 917.962 | 15 | 108936.97 | $4s''\,^4P_{2\frac{1}{2}} - s\,^4D^\circ_{2\frac{1}{2}}$ |
| 918.022 | 3 | 108929.85 | |
| 918.946 | 4 | 108820.32 | |
| 918.994 | 150 | 108814.64 | $4s''\,^4P_{2\frac{1}{2}} - s\,^4D^\circ_{3\frac{1}{2}}$ |
| 920.451 | 10 | 108642.39 | $4s\,^4F_{3\frac{1}{2}} - w\,^4F^\circ_{3\frac{1}{2}}$ |
| 921.228 | 2 | 108550.76 | |
| 921.299 | 1 | 108542.39 | $4s\,^4F_{3\frac{1}{2}} - 5p'\,^2D^\circ_{2\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 921.730 | 75 | 108491.64 | $4s''\ ^4P_{2^1/_2} - v\ ^4F^\circ_{3^1/_2}$ |
| 922.176 | 5 | 108439.17 | |
| 922.331 | 15 | 108420.95 | $4s''\ ^4P_{1^1/_2} - v\ ^4F^\circ_{2^1/_2}$ |
| 922.571 | 1 | 108392.74 | |
| 924.710 | 1 | 108142.01 | $4s\ ^2F_{3^1/_2} - x\ ^2G^\circ_{4^1/_2}$ |
| 924.783 | 10 | 108133.48 | $4s''\ ^4P_{2^1/_2} - w\ ^2F^\circ_{3^1/_2}$ |
| 924.912 | 20 | 108118.39 | $4s\ ^4F_{4^1/_2} - v\ ^4D^\circ_{3^1/_2}$ |
| 925.100 | 2 | 108096.42 | |
| 925.544 | 3 | 108044.57 | |
| 925.578 | 1 | 108040.60 | |
| 927.820 | 5 | 107779.53 | $4s\ ^4F_{1^1/_2} - 5p'\ ^2P^\circ_{1^1/_2}$? |
| 928.953 | 3 | 107648.07 | $4s\ ^4F_{2^1/_2} - 5p'\ ^2D^\circ_{1^1/_2}$ |
| 929.586 | 1 | 107574.77 | |
| 929.681 | 3 | 107563.78 | $4s\ ^4F_{3^1/_2} - v\ ^4D^\circ_{2^1/_2}$ |
| 929.831 | 5 | 107546.42 | $4s\ ^4F_{2^1/_2} - v\ ^4D^\circ_{1^1/_2}$ |
| 930.351 | 10 | 107486.31 | |
| 930.707 | 3h | 107445.20 | |
| 931.191 | 1h | 107389.35 | $4s''\ ^4P_{2^1/_2} - v\ ^4P^\circ_{1^1/_2}$ |
| 931.501 | 2 | 107353.62 | $4s\ ^2F_{3^1/_2} - 5p''\ ^4D^\circ_{3^1/_2}$ |
| 932.321 | 2 | 107259.19 | |
| 933.339 | 2 | 107142.21 | $3d\ ^2D_{2^1/_2} - 5p\ ^2D^\circ_{1^1/_2}$ |
| 933.421 | 1 | 107132.79 | |
| 933.866 | 1 | 107081.74 | $3d\ ^2D_{2^1/_2} - 5p\ ^2F^\circ_{2^1/_2}$ |
| 935.085 | 2 | 106942.15 | |
| 935.200 | 1 | 106929.00 | |
| 936.188 | 1 | 106816.15 | $4s\ ^4F_{4^1/_2} - x\ ^4G^\circ_{3^1/_2}$ |
| 936.704 | 15 | 106757.31 | $4s\ ^4F_{3^1/_2} - w\ ^4G^\circ_{4^1/_2}$ |
| 939.276 | 30 | 106464.98 | $4s\ ^4F_{4^1/_2} - w\ ^4G^\circ_{5^1/_2}$ |
| 940.886 | 20 | 106282.80 | $3d\ ^2D_{2^1/_2} - 5p\ ^4G^\circ_{2^1/_2}$ |
| 941.972 | 10 | 106160.27 | $4s\ ^4F_{2^1/_2} - w\ ^4G^\circ_{3^1/_2}$ |
| | | | $4s\ ^4F_{1^1/_2} - w\ ^4G^\circ_{2^1/_2}$ |
| 941.996 | 4 | 106157.56 | |
| 942.360 | 2 | 106116.56 | |
| 942.587 | 5 | 106091.00 | |
| 944.343 | 1 | 105893.73 | $4s''\ ^2P_{1^1/_2} - w\ ^2D^\circ_{1^1/_2}$ |
| 944.634 | 30 | 105861.11 | $3d\ ^2D_{2^1/_2} - 5p\ ^2D^\circ_{2^1/_2}$ |
| 944.842 | 10 | 105837.80 | $3d\ ^2D_{2^1/_2} - 5p\ ^2F^\circ_{3^1/_2}$ |
| 945.965 | 75 | 105712.16 | $5s''\ ^2P_{1^1/_2} - w\ ^2D^\circ_{2^1/_2}$ |
| 946.657 | 15 | 105634.88 | $3d\ ^2D_{1^1/_2} - 5p\ ^2D^\circ_{1^1/_2}$ |
| 946.769 | 3 | 105622.38 | $4s'''\ ^2G_{4^1/_2} - 9p\ ^4F^\circ_{4^1/_2}$? |
| 947.195 | 2 | 105574.88 | $3d\ ^2D_{1^1/_2} - 5p\ ^2F^\circ_{2^1/_2}$ |
| 949.024 | 0 | 105371.41 | $4s''\ ^2P_{0^1/_2} - w\ ^2D^\circ_{1^1/_2}$ |
| 949.137 | 1 | 105358.87 | $4s\ ^4F_{4^1/_2} - x\ ^4G^\circ_{4^1/_2}$ |
| 952.027 | 1 | 105039.04 | $4s'''\ ^2G_{3^1/_2} - 8p\ ^2G^\circ_{3^1/_2}$ |
| 952.266 | 8 | 105012.67 | $4s\ ^2F_{3^1/_2} - 5p'\ ^2F^\circ_{3^1/_2}$ |
| 952.340 | 1 | 105004.51 | $4s\ ^4F_{2^1/_2} - x\ ^4F^\circ_{2^1/_2}$ |
| 953.033 | 10 | 104928.16 | $4s\ ^4F_{4^1/_2} - x\ ^4F^\circ_{4^1/_2}$ |
| | | | $4s\ ^4F_{1^1/_2} - x\ ^4F^\circ_{1^1/_2}$ |
| 953.937 | 2 | 104828.73 | $4s\ ^2F_{3^1/_2} - 5p\ ^2F^\circ_{2^1/_2}$ |
| 954.911 | 1 | 104721.80 | $4s\ ^4F_{3^1/_2} - x\ ^4F^\circ_{3^1/_2}$ |
| 955.601 | 10 | 104646.19 | $3d\ ^2D_{2^1/_2} - 5p\ ^4F^\circ_{3^1/_2}$ |
| 956.912 | 3 | 104502.82 | $3d\ ^2D_{2^1/_2} - 5p\ ^4D^\circ_{2^1/_2}$ |
| 959.931 | 5 | 104174.15 | $4s'''\ ^2G_{4^1/_2} - 8p\ ^2G^\circ_{4^1/_2}$ |
| 960.261 | 5 | 104138.35 | $4s''\ ^2P_{1^1/_2} - v\ ^4F^\circ_{2^1/_2}$ |
| 960.269 | 5 | 104137.49 | |
| 961.516 | 1 | 104002.43 | |
| 962.526 | 1 | 103893.30 | $4s'''\ ^2G_{4^1/_2} - 6p'\ ^2F^\circ_{3^1/_2}$ |
| 962.750 | 1 | 103869.12 | $4s'''\ ^2G_{3^1/_2} - 6p'\ ^2F^\circ_{3^1/_2}$ |
| 963.855 | 15 | 103750.04 | |
| 965.470 | 20 | 103576.50 | $4s'''\ ^2G_{4^1/_2} - v\ ^2G^\circ_{4^1/_2}$ |
| 968.784 | 20 | 103222.18 | $4s'''\ ^2G_{3^1/_2} - v\ ^2G^\circ_{3^1/_2}$ |
| 971.415 | 50 | 102942.61 | $4s'\ ^2D_{1^1/_2} - x\ ^4S^\circ_{1^1/_2}$ |
| 973.121 | 1 | 102762.14 | $4s'''\ ^2G_{4^1/_2} - 8p\ ^4G^\circ_{4^1/_2}$ |
| 977.276 | 10 | 102325.24 | |
| 978.108 | 25 | 102238.20 | |
| 980.290 | 3 | 102010.63 | |
| 981.768 | 50 | 101857.06 | $4s'''\ ^2G_{3^1/_2} - w\ ^2G^\circ_{3^1/_2}$ |
| 983.004 | 3 | 101728.99 | |
| 983.431 | 1 | 101684.82 | $4s'''\ ^2G_{3^1/_2} - w\ ^2F^\circ_{2^1/_2}$ |
| 983.592 | 2 | 101668.17 | $4s\ ^4F_{2^1/_2} - y\ ^4G^\circ_{3^1/_2}$ |
| 985.918 | 10 | 101428.31 | |
| 986.992 | 2 | 101317.94 | |
| 987.339 | 4 | 101282.34 | |
| 988.338 | 10 | 101179.96 | |
| 990.626 | 100 | 100946.27 | $4s'''\ ^2G_{4^1/_2} - w\ ^2G^\circ_{4^1/_2}$ |
| 992.516 | 20 | 100754.04 | $4s\ ^4F_{4^1/_2} - y\ ^4F^\circ_{4^1/_2}$ |
| 993.128 | 15 | 100691.96 | $4s\ ^4F_{3^1/_2} - y\ ^4G^\circ_{4^1/_2}$ |
| 993.341 | 1 | 100670.36 | $4s'''\ ^2G_{4^1/_2} - w\ ^2F^\circ_{3^1/_2}$ |
| 994.867 | 10h | 100515.95 | $4s\ ^4F_{3^1/_2} - y\ ^4F^\circ_{3^1/_2}$ |
| 995.256 | 30 | 100476.66 | |
| 995.445 | 4 | 100457.58 | $4s\ ^4F_{2^1/_2} - y\ ^4F^\circ_{2^1/_2}$ |
| 995.453 | 3 | 100456.78 | $4s\ ^4F_{1^1/_2} - y\ ^4F^\circ_{1^1/_2}$ |
| 997.974 | 1 | 100203.01 | $4s\ ^2F_{3^1/_2} - x\ ^4G^\circ_{4^1/_2}$ |
| 1004.170 | 5 | 99584.73 | |
| 1005.021 | 8 | 99500.41 | |
| 1006.712 | 1 | 99333.27 | |
| 1008.218 | 10 | 99184.90 | |
| 1016.622 | 20 | 98364.98 | |
| 1016.677 | 8 | 98359.66 | |
| 1019.067 | 5 | 98128.97 | |
| 1021.060 | 5 | 97937.44 | |
| 1023.961 | 3 | 97659.97 | $4s'\ ^2D_{1^1/_2} - 4p''\ ^4S^\circ_{1^1/_2}$ |
| 1023.999 | 15 | 97656.34 | |
| 1024.720 | 50 | 97587.63 | $4s\ ^4F_{4^1/_2} - y\ ^6D^\circ_{3^1/_2}$ |
| 1025.591 | 2 | 97504.75 | |
| 1025.641 | 5 | 97500.00 | |
| 1026.981 | 5 | 97372.78 | |
| 1028.208 | 20 | 97256.59 | |
| 1031.306 | 1 | 96964.43 | $4s''\ ^4P_{0^1/_2} - 5p''\ ^2D^\circ_{1^1/_2}$ |
| 1032.749 | 2 | 96828.95 | |
| 1033.443 | 10 | 96763.92 | $4s''\ ^4P_{2^1/_2} - 5p''\ ^2D^\circ_{1^1/_2}$ |
| 1034.155 | 15 | 96697.30 | |
| 1034.249 | 10 | 96688.52 | $4s'\ ^2D_{1^1/_2} - 5p''\ ^4P^\circ_{2^1/_2}$ |
| 1036.182 | 2 | 96508.14 | $4s\ ^4F_{3^1/_2} - 5p\ ^2F^\circ_{3^1/_2}$ |
| 1038.866 | 5 | 96258.80 | $4s\ ^4F_{4^1/_2} - 5p\ ^2G^\circ_{4^1/_2}$ |
| 1040.668 | 1 | 96092.12 | |
| 1042.704 | 2 | 95904.49 | $4s\ ^4F_{4^1/_2} - 5p\ ^4G^\circ_{4^1/_2}$ |
| 1044.349 | 30 | 95753.43 | $4s\ ^4F_{4^1/_2} - 5p\ ^4G^\circ_{5^1/_2}$ |
| 1044.871 | 2 | 95705.59 | $4s\ ^4F_{1^1/_2} - 5p\ ^4F^\circ_{1^1/_2}$ |
| 1045.073 | 15 | 95687.10 | $4s\ ^4F_{4^1/_2} - 5p\ ^4F^\circ_{4^1/_2}$ |
| 1045.813 | 5 | 95619.39 | $4s\ ^4F_{1^1/_2} - 5p\ ^4G^\circ_{2^1/_2}$ |
| 1046.537 | 8 | 95553.24 | $4s\ ^4F_{2^1/_2} - 5p\ ^4F^\circ_{2^1/_2}$ |
| 1047.497 | 1 | 95465.67 | |
| 1048.400 | 6 | 95383.44 | $4s\ ^4F_{2^1/_2} - 5p\ ^4G^\circ_{3^1/_2}$ |
| 1048.936 | 1 | 95334.70 | $4s'\ ^2D_{2^1/_2} - 5p'\ ^2P^\circ_{1^1/_2}$ |
| 1048.982 | 3 | 95330.52 | $4s''\ ^4P_{0^1/_2} - 5p''\ ^4P^\circ_{1^1/_2}$ |
| 1049.051 | 1 | 95324.25 | $4s\ ^4F_{2^1/_2} - 5p\ ^4D^\circ_{1^1/_2}$ |
| 1049.137 | 8 | 95316.44 | $4s\ ^4F_{3^1/_2} - 5p\ ^4F^\circ_{3^1/_2}$ |
| 1049.755 | 100 | 95260.32 | $4s\ ^4F_{4^1/_2} - 5p\ ^4D^\circ_{3^1/_2}$ |
| 1050.718 | 3 | 95173.01 | $4s\ ^4F_{3^1/_2} - 5p\ ^4D^\circ_{2^1/_2}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 1052.534 | 10 | 95008.81 | $4s''\ ^4P_{1\frac{1}{2}} - 5p''\ ^4P^\circ_{2\frac{1}{2}}$ |
| 1052.983 | 2 | 94968.29 | $4s\ ^4F_{3\frac{1}{2}} - 5p\ ^4G^\circ_{4\frac{1}{2}}$ |
| 1053.729 | 15 | 94901.06 | |
| 1055.246 | 15 | 94764.63 | $4s'\ ^2D_{2\frac{1}{2}} - 5p'\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1055.291 | 30 | 94760.59 | $4s''\ ^4P_{2\frac{1}{2}} - 5p''\ ^4P^\circ_{2\frac{1}{2}}$ |
| 1056.837 | 2h | 94621.97 | |
| 1062.243 | 1 | 94140.42 | |
| 1062.965 | 1 | 94076.47 | $4s'\ ^2D_{1\frac{1}{2}} - 5p'\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1066.476 | 1 | 93766.76 | |
| 1070.590 | 10 | 93406.44 | $4s''\ ^4P_{2\frac{1}{2}} - 5p'\ ^2P^\circ_{1\frac{1}{2}}$ |
| 1074.224 | 1 | 93090.45 | |
| 1075.551 | 3 | 92975.60 | $4s''\ ^4P_{1\frac{1}{2}} - 5p'\ ^2D^\circ_{1\frac{1}{2}}$ |
| 1076.006 | 2 | 92936.28 | $4s''\ ^4P_{2\frac{1}{2}} - w\ ^4F^\circ_{3\frac{1}{2}}$ |
| 1077.163 | 4 | 92836.46 | $4s''\ ^4P_{2\frac{1}{2}} - 5p'\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1081.035 | 200 | 92503.94 | $4s'''\ ^2G_{4\frac{1}{2}} - y\ ^2H^\circ_{5\frac{1}{2}}$ |
| 1085.441 | 150 | 92128.45 | $4s'''\ ^2G_{3\frac{1}{2}} - y\ ^2H^\circ_{4\frac{1}{2}}$ |
| 1086.503 | 4 | 92038.40 | $4s\ ^2F_{3\frac{1}{2}} - 5p\ ^2G^\circ_{4\frac{1}{2}}$ |
| 1091.407 | 4 | 91624.85 | $4s\ ^2F_{2\frac{1}{2}} - 5p\ ^2G^\circ_{3\frac{1}{2}}$ |
| 1099.471 | 1 | 90952.83 | $4s\ ^2F_{3\frac{1}{2}} - 5p\ ^4D^\circ_{2\frac{1}{2}}$ |
| 1101.893 | 2 | 90752.91 | |
| 1101.956 | 5 | 90747.72 | $4s\ ^2F_{3\frac{1}{2}} - 5p\ ^4G^\circ_{4\frac{1}{2}}$ |
| 1104.602 | 1 | 90530.34 | $4s\ ^2F_{3\frac{1}{2}} - 5p\ ^4F^\circ_{4\frac{1}{2}}$ |
| 1105.315 | 1 | 90471.95 | |
| 1108.729 | 30 | 90193.37 | |
| 1109.022 | 1 | 90169.54 | |
| 1114.260 | 2 | 89745.66 | |
| 1116.557 | 40 | 89561.03 | $4s''\ ^2P_{1\frac{1}{2}} - 5p'\ ^2P^\circ_{0\frac{1}{2}}$ |
| 1118.404 | 20 | 89413.13 | |
| 1118.547 | 25 | 89401.70 | |
| 1118.921 | 10 | 89371.81 | $4s''\ ^2P_{1\frac{1}{2}} - 5p'\ ^2P^\circ_{1\frac{1}{2}}$ |
| 1119.330 | 75 | 89339.16 | $4s'''\ ^2G_{3\frac{1}{2}} - x\ ^2G^\circ_{3\frac{1}{2}}$ |
| 1121.162 | 125 | 89193.18 | $4s'''\ ^2G_{4\frac{1}{2}} - x\ ^2G^\circ_{4\frac{1}{2}}$ |
| 1123.113 | 2 | 89038.23 | $4s''\ ^2P_{0\frac{1}{2}} - 5p'\ ^2P^\circ_{0\frac{1}{2}}$ |
| 1127.112 | 4 | 88722.33 | |
| 1127.486 | 5 | 88692.90 | $4s''\ ^2P_{1\frac{1}{2}} - 5p'\ ^2D^\circ_{1\frac{1}{2}}$ |
| 1133.730 | 75 | 88204.42 | $4s\ ^2F_{3\frac{1}{2}} - z\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1134.533 | 150 | 88141.99 | $4s\ ^4F_{4\frac{1}{2}} - z\ ^4D^\circ_{3\frac{1}{2}}$ |
| 1135.412 | 1 | 88073.76 | |
| 1136.360 | 1 | 88000.28 | |
| 1137.091 | 100 | 87943.71 | $4s\ ^4F_{3\frac{1}{2}} - z\ ^4D^\circ_{2\frac{1}{2}}$ |
| 1138.547 | 10 | 87831.24 | |
| 1139.009 | 3 | 87795.62 | $s^2\ ^4F_{4\frac{1}{2}} - 6p''\ ^4D^\circ_{3\frac{1}{2}}$ |
| 1139.638 | 75 | 87747.16 | $4s\ ^2F_{2\frac{1}{2}} - z\ ^2D^\circ_{1\frac{1}{2}}$ |
| 1140.459 | 75 | 87683.99 | $4s\ ^4F_{2\frac{1}{2}} - z\ ^4D^\circ_{1\frac{1}{2}}$ |
| 1141.579 | 2 | 87597.97 | |
| 1141.891 | 1 | 87574.03 | |
| 1143.397 | 50 | 87458.69 | $4s\ ^4F_{1\frac{1}{2}} - z\ ^4D^\circ_{0\frac{1}{2}}$ |
| 1144.874 | 5 | 87345.86 | |
| 1147.633 | 1 | 87135.87 | $4s\ ^4F_{1\frac{1}{2}} - z\ ^4D^\circ_{1\frac{1}{2}}$ |
| 1149.239 | 1 | 87014.10 | |
| 1153.439 | 2 | 86697.26 | |
| 1154.416 | 150 | 86623.89 | $4s\ ^4F_{4\frac{1}{2}} - z\ ^4G^\circ_{4\frac{1}{2}}$ |
| 1156.319 | 2 | 86481.33 | |
| 1157.132 | 1 | 86420.56 | |
| 1158.830 | 100 | 86293.93 | $4s\ ^2F_{3\frac{1}{2}} - z\ ^2G^\circ_{4\frac{1}{2}}$ |
| 1159.510 | 150 | 86243.33 | $4s\ ^4F_{3\frac{1}{2}} - z\ ^4G^\circ_{3\frac{1}{2}}$ |
| 1160.776 | 2d | 86149.26 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 8d\ ^4D_{3\frac{1}{2}}$ |
| | | | $4p\ ^4D^\circ_{3\frac{1}{2}} - 8d\ ^4P_{2\frac{1}{2}}$ |
| 1160.823 | 1 | 86145.78 | |
| 1161.297 | 15d | 86110.62 | |
| 1161.927 | 1 | 86063.93 | $4s'''\ ^2G_{4\frac{1}{2}} - 5p\ ^2F^\circ_{3\frac{1}{2}}$ |
| 1162.361 | 1 | 86031.79 | |
| 1162.492 | 8 | 86022.10 | |
| 1162.601 | 1 | 86014.03 | |
| 1162.748 | 150 | 86003.16 | $4s\ ^4F_{4\frac{1}{2}} - z\ ^4G^\circ_{5\frac{1}{2}}$ |
| 1163.645 | 50 | 85936.86 | $4s\ ^4F_{2\frac{1}{2}} - z\ ^4G^\circ_{2\frac{1}{2}}$ |
| 1163.729 | 8 | 85930.66 | $4s'\ ^2D_{2\frac{1}{2}} - z\ ^6P^\circ_{1\frac{1}{2}}$ |
| 1163.880 | 4 | 85919.51 | |
| 1164.279 | 150 | 85890.06 | $4s\ ^4F_{4\frac{1}{2}} - z\ ^4F^\circ_{4\frac{1}{2}}$ |
| 1164.574 | 100 | 85868.31 | $4s\ ^2F_{3\frac{1}{2}} - z\ ^2F^\circ_{3\frac{1}{2}}$ |
| 1165.646 | 5 | 85789.34 | |
| 1165.798 | 12 | 85778.15 | $4s\ ^4F_{2\frac{1}{2}} - z\ ^4F^\circ_{1\frac{1}{2}}$ |
| 1167.030 | 25 | 85687.60 | $4s\ ^4F_{3\frac{1}{2}} - z\ ^4G^\circ_{4\frac{1}{2}}$ |
| 1167.803 | 10 | 85630.88 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 9s\ ^4F_{4\frac{1}{2}}$ |
| 1168.040 | 75 | 85613.51 | $4s\ ^2F_{2\frac{1}{2}} - z\ ^2F^\circ_{2\frac{1}{2}}$ |
| 1169.919 | 3 | 85476.00 | |
| 1170.169 | 20 | 85457.74 | $4s\ ^4F_{2\frac{1}{2}} - z\ ^4G^\circ_{3\frac{1}{2}}$ |
| 1171.117 | 15 | 85388.56 | $4s\ ^4F_{1\frac{1}{2}} - z\ ^4G^\circ_{2\frac{1}{2}}$ |
| 1171.291 | 100 | 85375.88 | $4s\ ^4F_{3\frac{1}{2}} - z\ ^4F^\circ_{3\frac{1}{2}}$ |
| 1173.121 | 1 | 85242.70 | $4s'\ ^2D_{1\frac{1}{2}} - z\ ^6P^\circ_{1\frac{1}{2}}$ |
| 1173.298 | 50 | 85229.84 | $4s\ ^4F_{1\frac{1}{2}} - z\ ^4F^\circ_{1\frac{1}{2}}$ |
| 1173.477 | 75 | 85216.84 | $4s\ ^4F_{2\frac{1}{2}} - z\ ^4F^\circ_{2\frac{1}{2}}$ |
| 1177.006 | 1 | 84961.33 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 4d''\ ^4F_{4\frac{1}{2}}$ |
| 1177.109 | 50 | 84953.90 | $4s\ ^4F_{3\frac{1}{2}} - z\ ^4F^\circ_{4\frac{1}{2}}$ |
| 1178.224 | 8d | 84873.50 | |
| 1178.571 | 30 | 84848.52 | $4s\ ^2F_{2\frac{1}{2}} - z\ ^2G^\circ_{3\frac{1}{2}}$ |
| 1180.271 | 150 | 84726.30 | $4s\ ^2F_{3\frac{1}{2}} - z\ ^2G^\circ_{4\frac{1}{2}}$ |
| 1181.075 | 30 | 84668.63 | $4s\ ^4F_{1\frac{1}{2}} - z\ ^4F^\circ_{2\frac{1}{2}}$ |
| 1181.620 | 15 | 84629.58 | $4s'\ ^2D_{2\frac{1}{2}} - z\ ^4S^\circ_{1\frac{1}{2}}$ |
| 1182.169 | 75 | 84590.27 | $4s\ ^4F_{2\frac{1}{2}} - z\ ^4F^\circ_{3\frac{1}{2}}$ |
| 1184.512 | 20 | 84422.95 | $4s\ ^2F_{2\frac{1}{2}} - z\ ^2F^\circ_{3\frac{1}{2}}$ |
| 1184.980 | 3 | 84389.61 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 8d\ ^4G_{5\frac{1}{2}}$ |
| 1185.146 | 2 | 84377.79 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 8d\ ^4H_{5\frac{1}{2}}$ |
| 1186.347 | 1 | 84292.37 | |
| 1186.933 | 8 | 84250.75 | $4s''\ ^4P_{1\frac{1}{2}} - z\ ^6P^\circ_{1\frac{1}{2}}$ |
| 1186.993 | 1 | 84246.50 | $4p\ ^4G^\circ_{5\frac{1}{2}} - 8d\ ^4H_{5\frac{1}{2}}$ |
| 1187.102 | 20 | 84238.76 | $4p\ ^4G^\circ_{5\frac{1}{2}} - 8d\ ^4H_{6\frac{1}{2}}$ |
| 1187.608 | 15 | 84202.87 | $4s''\ ^4P_{0\frac{1}{2}} - z\ ^6P^\circ_{1\frac{1}{2}}$ |
| 1190.442 | 1 | 84002.41 | $4s''\ ^4P_{2\frac{1}{2}} - z\ ^6P^\circ_{1\frac{1}{2}}$ |
| 1192.306 | 5 | 83871.09 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 9s\ ^4F_{3\frac{1}{2}}$ |
| 1192.596 | 00 | 83850.69 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 5d''\ ^4F_{3\frac{1}{2}}$ |
| 1192.983 | 3 | 83823.49 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 9s\ ^4F_{4\frac{1}{2}}$ |
| 1193.028 | 2 | 83820.33 | |
| 1193.267 | 5h? | 83803.54 | |
| 1194.857 | 15 | 83692.02 | $4p\ ^4G^\circ_{5\frac{1}{2}} - 9s\ ^4F_{4\frac{1}{2}}$ |
| 1200.077 | 1 | 83327.99 | |
| 1200.307 | 1 | 83312.02 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 8s\ ^2F_{2\frac{1}{2}}$ |
| 1201.002 | 3h | 83263.81 | $4p\ ^2G^\circ_{4\frac{1}{2}} - 9s\ ^2F_{3\frac{1}{2}}$ |
| 1201.119 | 8 | 83255.70 | $s^2\ ^4F_{3\frac{1}{2}} - 4f'''\ ^4F^\circ_{2\frac{1}{2}}$ |
| 1201.838 | 5 | 83205.89 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 7d\ ^2F_{3\frac{1}{2}}$ |
| 1201.957 | 3 | 83197.65 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 8d\ ^4G_{5\frac{1}{2}}$ |
| 1202.452 | 8 | 83163.40 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 7d\ ^4F_{2\frac{1}{2}}$ |
| 1202.511 | 10 | 83159.32 | |
| 1202.911 | 3 | 83131.67 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 5d''\ ^4F_{2\frac{1}{2}}$ |
| 1204.102 | 30 | 83049.44 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 7d\ ^4F_{4\frac{1}{2}}$ |
| 1205.088 | 15 | 82981.49 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 7d\ ^4P_{2\frac{1}{2}}$ |
| 1205.201 | 1 | 82973.71 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 9s\ ^4F_{3\frac{1}{2}}$ |
| 1205.266 | 20 | 82969.24 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 7d\ ^4D_{3\frac{1}{2}}$ |
| 1205.314 | 8 | 82965.93 | |
| 1205.552 | 10 | 82949.55 | $4s''\ ^4P_{1\frac{1}{2}} - z\ ^4S^\circ_{1\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 1206.246 | 7 | 82901.83 | $4s''\ ^4P_{0\,1/2} - z\ ^4S^\circ_{1\,1/2}$ |
| 1207.567 | 0 | 82811.14 | $s^2\ ^4F_{2\,1/2} - 4f''\ ^4D^\circ_{2\,1/2}$ |
| 1207.620 | 4 | 82807.51 | $s^2\ ^4F_{4\,1/2} - v\ ^4F^\circ_{4\,1/2}$ |
| 1207.654 | 3 | 82805.17 | $s^2\ ^4F_{4\,1/2} - s\ ^4D^\circ_{3\,1/2}$ |
| 1208.433 | 1 | 82751.79 | $4s'\ ^2D_{2\,1/2} - 5p\ ^2D^\circ_{2\,1/2}$? |
| 1209.170 | 7 | 82701.36 | $4s''\ ^4P_{2\,1/2} - z\ ^4S^\circ_{1\,1/2}$ |
| 1209.492 | 1 | 82679.34 | $4p\ ^4F^\circ_{4\,1/2} - 9s\ ^4F_{3\,1/2}$ |
| 1210.192 | 10 | 82631.52 | $4p\ ^4F^\circ_{4\,1/2} - 9s\ ^4F_{4\,1/2}$ |
| 1210.729 | 3 | 82594.87 | $4p\ ^4G^\circ_{4\,1/2} - 7d\ ^4H_{4\,1/2}$ |
| 1210.790 | 1 | 82590.71 | $4p\ ^4G^\circ_{4\,1/2} - 7d\ ^2H_{5\,1/2}$ |
| 1211.403 | 1 | 82548.91 | $4p\ ^4D^\circ_{0\,1/2} - 5d''\ ^4P_{0\,1/2}$ |
| 1212.959 | 0 | 82443.02 | $4p\ ^2G^\circ_{4\,1/2} - 8d\ ^4H_{5\,1/2}$ |
| 1213.149 | 7 | 82430.10 | |
| 1213.361 | 7 | 82415.70 | $4p\ ^4D^\circ_{1\,1/2} - 8s\ ^2F_{2\,1/2}$ |
| 1214.104 | 3 | 82365.27 | $4p\ ^4D^\circ_{3\,1/2} - 5d'\ ^2G_{4\,1/2}$ |
| 1214.153 | 40 | 82361.94 | $4p\ ^4D^\circ_{2\,1/2} - 8s\ ^2F_{3\,1/2}$ |
| 1214.350 | 1 | 82348.58 | $4p\ ^4D^\circ_{1\,1/2} - 8s\ ^4F_{1\,1/2}$ |
| 1217.180 | 100 | 82157.12 | $4p\ ^4D^\circ_{3\,1/2} - 8s\ ^4F_{4\,1/2}$ |
| 1217.692 | 1 | 82122.57 | |
| 1220.530 | 3 | 81931.62 | $4p\ ^4D^\circ_{2\,1/2} - 7d\ ^4P_{1\,1/2}$ |
| 1220.950 | 1 | 81903.44 | $4p\ ^4D^\circ_{2\,1/2} - 7d\ ^4F_{3\,1/2}$ |
| 1221.213 | 1 | 81885.80 | $4p\ ^4D^\circ_{3\,1/2} - 6s''\ ^4P_{2\,1/2}$ |
| 1221.289 | 1 | 81880.70 | $4p\ ^4G^\circ_{2\,1/2} - 7d\ ^4G_{2\,1/2}$ |
| 1221.992 | 40 | 81833.60 | $4p\ ^4G^\circ_{2\,1/2} - 7d\ ^4F_{1\,1/2}$ |
| 1222.220 | 1 | 81818.33 | $4p\ ^4F^\circ_{3\,1/2} - 9s\ ^4F_{3\,1/2}$ |
| 1222.395 | 20 | 81806.62 | $4p\ ^4D^\circ_{0\,1/2} - 8s\ ^4F_{1\,1/2}$ |
| 1222.678 | 1 | 81787.68 | $4p\ ^4G^\circ_{3\,1/2} - 8s\ ^2F_{2\,1/2}$ |
| 1222.989 | 1 | 81766.88 | $s^2\ ^4F_{3\,1/2} - s\ ^4D^\circ_{2\,1/2}$ |
| 1223.466 | 2 | 81735.00 | $4p\ ^4G^\circ_{4\,1/2} - 8s\ ^2F_{3\,1/2}$ |
| 1223.643 | 5 | 81723.18 | $4p\ ^4G^\circ_{3\,1/2} - 7d\ ^4G_{3\,1/2}$ |
| 1223.775 | 1 | 81714.37 | $4p\ ^4G^\circ_{3\,1/2} - 7d\ ^2G_{4\,1/2}$ |
| 1224.033 | 75 | 81697.14 | $4p\ ^4G^\circ_{3\,1/2} - 7d\ ^4H_{4\,1/2}$ |
| 1224.268 | 1 | 81681.46 | $4p\ ^4G^\circ_{3\,1/2} - 7d\ ^2F_{3\,1/2}$ |
| 1224.839 | 2 H? | 81643.38 | $4s'\ ^2D_{1\,1/2} - 5p\ ^4D^\circ_{1\,1/2}$ |
| 1226.628 | 25 | 81524.31 | $4s\ ^4F_{4\,1/2} - z\ ^6G^\circ_{4\,1/2}$ |
| 1227.267 | 15 | 81481.86 | $4p\ ^4D^\circ_{1\,1/2} - 8s\ ^4F_{2\,1/2}$ |
| 1227.491 | 5 | 81466.99 | $4s\ ^2F_{3\,1/2} - z\ ^4G^\circ_{4\,1/2}$ |
| 1228.581 | 0 | 81394.71 | $4s'\ ^2D_{2\,1/2} - 5p\ ^4D^\circ_{2\,1/2}$ |
| 1229.684 | 10 | 81321.70 | $s^2\ ^4F_{3\,1/2} - v\ ^4F^\circ_{3\,1/2}$ |
| 1230.116 | 8 | 81293.15 | $4p\ ^4G^\circ_{4\,1/2} - 7d\ ^4G_{4\,1/2}$ |
| 1230.367 | 1 | 81276.56 | $4p\ ^4G^\circ_{4\,1/2} - 7d\ ^4F_{3\,1/2}$ |
| 1230.782 | 40 | 81249.16 | $4p\ ^4G^\circ_{4\,1/2} - 7d\ ^4G_{5\,1/2}$ |
| 1230.869 | 50 | 81243.41 | |
| 1230.889 | 25 | 81242.09 | $4p\ ^4G^\circ_{4\,1/2} - 7d\ ^4F_{4\,1/2}$ |
| 1231.041 | 100 | 81232.06 | $4p\ ^4G^\circ_{4\,1/2} - 7d\ ^4H_{5\,1/2}$ |
| 1232.107 | 1 | 81161.78 | $4p\ ^4G^\circ_{4\,1/2} - 7d\ ^4D_{3\,1/2}$<br>$4p\ ^4G^\circ_{5\,1/2} - 7d\ ^4G_{4\,1/2}$ |
| 1232.773 | 2 | 81117.93 | $4p\ ^4G^\circ_{5\,1/2} - 7d\ ^4G_{5\,1/2}$ |
| 1232.886 | 3 | 81110.50 | $4p\ ^4G^\circ_{5\,1/2} - 7d\ ^4F_{4\,1/2}$ |
| 1233.036 | 15 | 81100.63 | $4p\ ^4G^\circ_{5\,1/2} - 7d\ ^4H_{5\,1/2}$ |
| 1233.250 | 150 | 81086.56 | $4p\ ^4G^\circ_{5\,1/2} - 7d\ ^4H_{6\,1/2}$ |
| 1233.484 | 10 | 81071.18 | $4p\ ^4D^\circ_{2\,1/2} - 8s\ ^4F_{3\,1/2}$ |
| 1233.557 | 100 | 81066.38 | $4s\ ^4F_{4\,1/2} - z\ ^6G^\circ_{5\,1/2}$ |
| 1234.092 | 0 | 81031.24 | $4p\ ^4G^\circ_{2\,1/2} - 8s\ ^2F_{2\,1/2}$ |
| 1234.375 | 4 | 81012.66 | $4p\ ^4G^\circ_{2\,1/2} - 7d\ ^2D_{2\,1/2}$ |
| 1234.659 | 1 | 80994.02 | |
| 1235.069 | 6 | 80967.14 | $4p\ ^4G^\circ_{2\,1/2} - 7d\ ^4G_{3\,1/2}$ |
| 1235.112 | 20 | 80964.32 | $4p\ ^4G^\circ_{2\,1/2} - 8s\ ^4F_{1\,1/2}$ |
| 1235.405 | 10 | 80945.12 | $4s\ ^4F_{3\,1/2} - z\ ^6G^\circ_{3\,1/2}$ |
| 1236.474 | 0 | 80875.13 | $4p\ ^4D^\circ_{2\,1/2} - 6s''\ ^4P_{1\,1/2}$ |
| 1236.799 | 25 | 80853.88 | $4p\ ^4G^\circ_{3\,1/2} - 8s\ ^4F_{2\,1/2}$ |
| 1237.049 | 10 | 80837.54 | $4p\ ^4G^\circ_{3\,1/2} - 8s\ ^2F_{3\,1/2}$ |
| 1237.247 | 1 | 80824.60 | $4s''\ ^4P_{2\,1/2} - 5p\ ^2D^\circ_{2\,1/2}$ |
| 1237.260 | 1 | 80823.76 | $4p\ ^4F^\circ_{2\,1/2} - 7d\ ^4G_{2\,1/2}$ |
| 1237.961 | 4 | 80777.99 | |
| 1237.976 | 8 | 80777.01 | $4p\ ^4F^\circ_{2\,1/2} - 7d\ ^4F_{1\,1/2}$ |
| 1238.919 | 1 | 80715.53 | $4p\ ^4G^\circ_{3\,1/2} - 7d\ ^4D_{2\,1/2}$ |
| 1239.061 | 25 | 80706.28 | $s^2\ ^4F_{3\,1/2} - 4f'\ ^2D^\circ_{2\,1/2}$ |
| 1239.506 | 12 | 80677.30 | $4p\ ^2G^\circ_{4\,1/2} - 7d\ ^2G_{4\,1/2}$ |
| 1239.832 | 60 | 80656.09 | $4p\ ^2G^\circ_{4\,1/2} - 7d\ ^2H_{5\,1/2}$ |
| 1240.012 | 1 | 80644.38 | $4p\ ^2G^\circ_{4\,1/2} - 7d\ ^2F_{3\,1/2}$ |
| 1240.029 | 2 | 80643.27 | |
| 1240.877 | 50 | 80588.16 | $4p\ ^2G^\circ_{3\,1/2} - 7d\ ^2F_{2\,1/2}$ |
| 1241.189 | 1 | 80567.91 | $4p\ ^4F^\circ_{3\,1/2} - 7d\ ^4G_{3\,1/2}$ |
| 1241.233 | 2 | 80565.05 | $4p\ ^2G^\circ_{3\,1/2} - 7d\ ^2G_{3\,1/2}$? |
| 1241.320 | 10 | 80559.40 | $4p\ ^4F^\circ_{3\,1/2} - 7d\ ^2G_{4\,1/2}$ |
| 1241.548 | 3 | 80544.61 | $4s'\ ^2D_{2\,1/2} - 5p\ ^4D^\circ_{3\,1/2}$ |
| 1241.588 | 10 | 80542.02 | $4p\ ^4F^\circ_{3\,1/2} - 7d\ ^4H_{4\,1/2}$ |
| 1241.827 | 1 | 80526.51 | $4p\ ^4F^\circ_{3\,1/2} - 7d\ ^2F_{3\,1/2}$ |
| 1242.099 | 30 | 80508.88 | $4p\ ^2G^\circ_{3\,1/2} - 7d\ ^2H_{4\,1/2}$ |
| 1242.627 | 6 | 80474.67 | $4p\ ^4F^\circ_{1\,1/2} - 7d\ ^4G_{2\,1/2}$ |
| 1243.093 | 75 | 80444.50 | $4p\ ^4G^\circ_{4\,1/2} - 8s\ ^4F_{3\,1/2}$ |
| 1243.126 | 6 | 80442.37 | |
| 1243.345 | 1 | 80428.20 | $4p\ ^4F^\circ_{1\,1/2} - 7d\ ^4F_{1\,1/2}$ |
| 1243.622 | 3 | 80410.29 | $4s\ ^4F_{2\,1/2} - z\ ^6G^\circ_{2\,1/2}$ |
| 1243.848 | 5 | 80395.67 | $4p\ ^4G^\circ_{3\,1/2} - 7d\ ^4G_{4\,1/2}$ |
| 1244.104 | 3 | 80379.13 | $4p\ ^4G^\circ_{3\,1/2} - 7d\ ^4F_{3\,1/2}$ |
| 1244.255 | 5 | 80369.38 | $4p\ ^4G^\circ_{4\,1/2} - 5d'\ ^2F_{3\,1/2}$ |
| 1244.560 | 50 | 80349.68 | $4p\ ^4G^\circ_{4\,1/2} - 8s\ ^4F_{4\,1/2}$ |
| 1244.811 | 100? | 80333.48 | |
| 1245.977 | 1 | 80258.30 | |
| 1246.598 | 150 | 80218.32 | $4p\ ^4G^\circ_{5\,1/2} - 8s\ ^4F_{4\,1/2}$ |
| 1247.333 | 20 | 80171.05 | $s^2\ ^4F_{2\,1/2} - v\ ^4F^\circ_{2\,1/2}$ |
| 1247.509 | 6 | 80159.74 | $4s\ ^4F_{2\,1/2} - z\ ^6G^\circ_{3\,1/2}$ |
| 1247.568 | 1 | 80155.95 | $4p\ ^2F^\circ_{3\,1/2} - 9s\ ^4F_{3\,1/2}$ |
| 1248.413 | 9 | 80101.70 | $4p\ ^4F^\circ_{4\,1/2} - 7d\ ^4G_{4\,1/2}$ |
| 1248.467 | 10 | 80098.23 | $4p\ ^4G^\circ_{2\,1/2} - 8s\ ^4F_{2\,1/2}$ |
| 1248.844 | 4 | 80074.05 | |
| 1249.101 | 100 | 80057.58 | $4p\ ^4F^\circ_{4\,1/2} - 7d\ ^4G_{5\,1/2}$ |
| 1249.213 | 8 | 80050.40 | $4p\ ^4F^\circ_{4\,1/2} - 7d\ ^4F_{4\,1/2}$ |
| 1249.369 | 3 | 80040.40 | $4p\ ^4F^\circ_{4\,1/2} - 7d\ ^4H_{5\,1/2}$ |
| 1250.467 | 6 | 79970.12 | $4p\ ^4F^\circ_{4\,1/2} - 7d\ ^4D_{3\,1/2}$ |
| 1250.685 | 4 | 79956.18 | $4p\ ^4F^\circ_{2\,1/2} - 7d\ ^2D_{2\,1/2}$ |
| 1250.901 | 1 | 79942.38 | |
| 1251.394 | 10 | 79910.88 | $4p\ ^4F^\circ_{2\,1/2} - 7d\ ^4G_{3\,1/2}$ |
| 1251.438 | 16 | 79908.07 | $4p\ ^4F^\circ_{2\,1/2} - 8s\ ^4F_{1\,1/2}$ |
| 1252.879 | 1 | 79816.17 | $4p\ ^2D^\circ_{2\,1/2} - 9s\ ^4F_{3\,1/2}$ |
| 1253.122 | 50 | 79800.69 | $4p\ ^2G^\circ_{4\,1/2} - 8s\ ^2F_{3\,1/2}$ |
| 1253.477 | 75 | 79778.09 | $4s\ ^4F_{4\,1/2} - z\ ^6D^\circ_{4\,1/2}$ |
| 1253.599 | 4 | 79770.33 | $4s\ ^4F_{3\,1/2} - z\ ^6D^\circ_{3\,1/2}$ |
| 1254.290 | 2 | 79726.38 | $4p\ ^4D^\circ_{0\,1/2} - 5d'\ ^2P_{0\,1/2}$ |
| 1254.346 | 00 | 79722.82 | $s^2\ ^4F_{3\,1/2} - 7p\ ^2G^\circ_{4\,1/2}$ |
| 1254.471 | 1 | 79714.88 | $4s''\ ^4P_{1\,1/2} - 5p\ ^4D^\circ_{2\,1/2}$ |
| 1254.721 | 50 | 79698.99 | $4p\ ^4F^\circ_{3\,1/2} - 8s\ ^4F_{2\,1/2}$ |
| 1254.978 | 7 | 79682.67 | $4p\ ^4F^\circ_{3\,1/2} - 8s\ ^2F_{3\,1/2}$ |
| 1255.034 | 8 | 79679.12 | $4p\ ^2G^\circ_{3\,1/2} - 8s\ ^2F_{2\,1/2}$ |
| 1255.335 | 6 | 79660.01 | $4p\ ^2G^\circ_{3\,1/2} - 7d\ ^2D_{2\,1/2}$ |
| 1256.029 | 5 | 79616.00 | $s^2\ ^4F_{4\,1/2} - 7p\ ^4G^\circ_{5\,1/2}$? |
| 1256.187 | 6 | 79605.98 | $4p\ ^2G^\circ_{3\,1/2} - 7d\ ^2G_{4\,1/2}$ |
| 1256.459 | 00 | 79588.75 | $4p\ ^2G^\circ_{3\,1/2} - 7d\ ^4H_{4\,1/2}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(vac) | Intensity | Wavenumber | Transition | λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|---|---|---|---|
| 1256.708 | 1 | 79572.98 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 7d\ ^2F_{3\frac{1}{2}}$ | 1287.329 | 15 | 77680.22 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 8s\ ^2F_{3\frac{1}{2}}$ |
| 1256.764 | 1 | 79569.43 | | 1287.432 | 8 | 77674.00 | |
| 1256.905 | 6 | 79560.51 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 7d\ ^4D_{2\frac{1}{2}}$ | 1289.024 | 9 | 77578.07 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 7d\ ^4G_{4\frac{1}{2}}$ |
| 1256.930 | 40 | 79558.93 | $4p\ ^4F^\circ_{1\frac{1}{2}} - 8s\ ^4F_{1\frac{1}{2}}$ | 1289.298 | 3 | 77561.59 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 7d\ ^4F_{3\frac{1}{2}}$ |
| 1257.116 | 8 | 79547.15 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 8s\ ^4F_{3\frac{1}{2}}$ | 1289.354 | 7 | 77558.22 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 5d'\ ^2G_{3\frac{1}{2}}$ |
| 1257.829 | 2 | 79502.06 | | | | | $4p\ ^2D^\circ_{2\frac{1}{2}} - 7d\ ^4D_{2\frac{1}{2}}$ |
| 1258.303 | 00 | 79472.11 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 5d'\ ^2F_{3\frac{1}{2}}$ | 1289.369 | 11 | 77557.32 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 8s\ ^2F_{2\frac{1}{2}}$ |
| 1259.506 | 1 | 79396.21 | | 1289.513 | 2 | 77548.66 | $4s''\ ^2P_{0\frac{1}{2}} - 5p\ ^2D^\circ_{1\frac{1}{2}}$ |
| 1259.886 | 1 | 79372.26 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 5d'\ ^2G_{3\frac{1}{2}}$ | 1289.656 | 6 | 77540.06 | $4s\ ^4F_{3\frac{1}{2}} - z\ ^6F^\circ_{4\frac{1}{2}}$ |
| 1261.068 | 1 | 79297.87 | $4p\ ^2G^\circ_{4\frac{1}{2}} - 7d\ ^4H_{5\frac{1}{2}}$ | 1289.682 | 1 | 77538.49 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 7d\ ^2D_{2\frac{1}{2}}$ |
| 1261.786 | 12 | 79252.74 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 8s\ ^4F_{3\frac{1}{2}}$ | 1290.442 | 1 | 77492.83 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 7d\ ^4G_{3\frac{1}{2}}$ |
| 1261.975 | 10 | 79240.87 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 7d\ ^4G_{4\frac{1}{2}}$ | 1290.908 | 4 | 77464.85 | $4s\ ^4F_{1\frac{1}{2}} - z\ ^6F^\circ_{2\frac{1}{2}}$ |
| 1262.239 | 8 | 79224.30 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 7d\ ^4F_{3\frac{1}{2}}$ | 1291.251 | 10 | 77444.28 | $4p\ ^4D^\circ_{0\frac{1}{2}} - 6d\ ^4F_{1\frac{1}{2}}$ |
| 1262.979 | 2 | 79177.88 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 5d'\ ^2F_{3\frac{1}{2}}$ | 1291.614 | 10 | 77422.51 | $4s\ ^4F_{2\frac{1}{2}} - z\ ^6F^\circ_{3\frac{1}{2}}$ |
| 1263.294 | 100 | 79158.14 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 8s\ ^4F_{4\frac{1}{2}}$ | 1292.033 | 2 | 77397.40 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 6d\ ^2D_{2\frac{1}{2}}$ |
| 1265.157 | 14 | 79041.57 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 8s\ ^4F_{2\frac{1}{2}}$ | 1292.224 | 2 | 77385.96 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 6d\ ^2H_{5\frac{1}{2}}$ |
| 1266.065 | 1 | 78984.89 | $4s\ ^4F_{2\frac{1}{2}} - z\ ^6D^\circ_{3\frac{1}{2}}$ | 1292.331 | 6 | 77379.56 | |
| 1266.608 | 8 | 78951.02 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 7d\ ^2D_{2\frac{1}{2}}$ | 1292.669 | 5 | 77359.32 | |
| 1267.478 | 6 | 78896.83 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 7d\ ^2G_{4\frac{1}{2}}$ | 1293.232 | 5 | 77325.65 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 7d\ ^2D_{2\frac{1}{2}}$ |
| 1268.007 | 8 | 78863.92 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 7d\ ^2F_{3\frac{1}{2}}$ | 1293.533 | 6 | 77307.65 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 6d\ ^4D_{1\frac{1}{2}}$ |
| 1268.359 | 2 | 78842.03 | $4s\ ^4F_{3\frac{1}{2}} - z\ ^6D^\circ_{4\frac{1}{2}}$ | 1294.500 | 10 | 77249.90 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 7d\ ^4P_{1\frac{1}{2}}$ |
| 1269.059 | 1 | 78798.54 | $4s\ ^4F_{3\frac{1}{2}} - z\ ^6F^\circ_{2\frac{1}{2}}$ | 1294.968 | 2 | 77221.98 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 7d\ ^4F_{3\frac{1}{2}}$ |
| 1269.917 | 2 | 78745.30 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 8s\ ^4F_{2\frac{1}{2}}$ | 1296.126 | 1 | 77152.99 | |
| 1270.061 | 1 | 78736.37 | $s^2\ ^4F_{4\frac{1}{2}} - t\ ^4D^\circ_{3\frac{1}{2}}$ | 1296.950 | 13 | 77103.97 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^4D_{2\frac{1}{2}}$ |
| 1270.180 | 15 | 78729.00 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 8s\ ^2F_{3\frac{1}{2}}$ | 1297.087 | 2 | 77095.83 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 6d\ ^4F_{2\frac{1}{2}}$ |
| 1271.993 | 1 | 78616.78 | $4s''\ ^4P_{2\frac{1}{2}} - 5p\ ^4D^\circ_{3\frac{1}{2}}$ | 1297.417 | 3 | 77076.22 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 6d\ ^4P_{0\frac{1}{2}}$ |
| 1272.080 | 1 | 78611.41 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 7d\ ^2D_{2\frac{1}{2}}$ | 1297.442 | 1 | 77074.74 | |
| 1272.634 | 2 | 78577.19 | | 1302.246 | 10 | 76790.41 | $4s''\ ^2P_{1\frac{1}{2}} - 5p\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1273.488 | 2 | 78524.49 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 7d\ ^2F_{3\frac{1}{2}}$ | 1302.603 | 1 | 76769.36 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 6d\ ^2D_{2\frac{1}{2}}$ |
| 1273.717 | 1 | 78510.37 | $4p\ ^2G^\circ_{4\frac{1}{2}} - 8s\ ^4F_{3\frac{1}{2}}$ | 1303.078 | 4 | 76741.38 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^4P_{1\frac{1}{2}}$ |
| 1274.180 | 2 | 78481.85 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 7d\ ^4F_{2\frac{1}{2}}$ | 1303.170 | 2 | 76735.96 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^4F_{3\frac{1}{2}}$ |
| 1274.270 | 100 | 78476.30 | $4s\ ^4F_{4\frac{1}{2}} - z\ ^6F^\circ_{4\frac{1}{2}}$ | 1303.237 | 00 | 76732.01 | $4p\ ^4G^\circ_{2\frac{1}{2}} - 6d\ ^2G_{3\frac{1}{2}}$ |
| 1274.802 | 10 | 78443.55 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 7d\ ^2G_{3\frac{1}{2}}$ | 1303.283 | 5 | 76729.30 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 8s\ ^4F_{3\frac{1}{2}}$ |
| 1275.640 | 10 | 78392.02 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 8s\ ^4F_{3\frac{1}{2}}$ | 1304.555 | 1 | 76654.49 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 5d'\ ^2F_{3\frac{1}{2}}$ |
| 1276.602 | 2 | 78332.95 | | 1304.594 | 10 | 76652.20 | $4p\ ^4G^\circ_{2\frac{1}{2}} - 6d\ ^4G_{2\frac{1}{2}}$ |
| 1276.859 | 1 | 78317.18 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 5d'\ ^2F_{3\frac{1}{2}}$ | 1305.083 | 6 | 76623.48 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 8s\ ^4F_{2\frac{1}{2}}$ |
| 1277.086 | 1 | 78303.26 | | 1305.169 | 25 | 76618.43 | $4p\ ^4G^\circ_{2\frac{1}{2}} - 6d\ ^4H_{3\frac{1}{2}}$ |
| 1277.243 | 20 | 78293.64 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^2D_{2\frac{1}{2}}$ | 1306.279 | 4 | 76553.32 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 6d\ ^4G_{3\frac{1}{2}}$ |
| 1277.344 | 1 | 78287.45 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 7d\ ^4G_{4\frac{1}{2}}$ | 1306.528 | 1 | 76538.73 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 6d\ ^2G_{4\frac{1}{2}}$ |
| 1277.617 | 1 | 78270.72 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 7d\ ^4F_{3\frac{1}{2}}$ | 1306.621 | 6 | 76533.29 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 7s\ ^2F_{3\frac{1}{2}}$ |
| 1277.725 | 2 | 78264.10 | | 1307.146 | 10 | 76502.55 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 6d\ ^2F_{3\frac{1}{2}}$ |
| 1277.967 | 18 | 78249.28 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 7d\ ^2P_{0\frac{1}{2}}$ | 1307.276 | 50 | 76494.94 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 6d\ ^4H_{4\frac{1}{2}}$ |
| 1278.637 | 100 | 78208.28 | $4s\ ^4F_{3\frac{1}{2}} - z\ ^6F^\circ_{3\frac{1}{2}}$ | 1308.714 | 8 | 76410.89 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 8s\ ^4F_{2\frac{1}{2}}$ |
| 1279.400 | 1 | 78161.64 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 6d\ ^2F_{2\frac{1}{2}}$ | 1308.869 | 16 | 76401.84 | |
| 1281.056 | 1 | 78060.60 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 5d''\ ^4F_{2\frac{1}{2}}$ | 1309.079 | 0 | 76389.58 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 8s\ ^4F_{3\frac{1}{2}}$ |
| 1281.609 | 5 | 78026.92 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 6s''\ ^4P_{2\frac{1}{2}}$ | 1310.358 | 1 | 76315.02 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 5d'\ ^2F_{3\frac{1}{2}}$ |
| | | | $4p\ ^2D^\circ_{1\frac{1}{2}} - 5d''\ ^4F_{1\frac{1}{2}}$ | 1310.457 | 15 | 76309.26 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 7s\ ^4F_{4\frac{1}{2}}$ |
| | | | $4p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^2F_{3\frac{1}{2}}$ | 1311.152 | 1 | 76268.81 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 6d\ ^2H_{4\frac{1}{2}}$ |
| 1281.704 | 4 | 78021.13 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 6d\ ^2P_{0\frac{1}{2}}$ | 1311.365 | 5 | 76256.42 | |
| 1281.723 | 12 | 78019.98 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 8s\ ^2F_{3\frac{1}{2}}$ | 1313.403 | 7 | 76138.09 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 6d\ ^4G_{4\frac{1}{2}}$ |
| 1281.834 | 50 | 78013.22 | $4s\ ^4F_{2\frac{1}{2}} - z\ ^6F^\circ_{2\frac{1}{2}}$? | 1313.903 | 2 | 76109.12 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 6d\ ^4F_{3\frac{1}{2}}$ |
| 1282.179 | 2 | 77992.23 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^4F_{2\frac{1}{2}}$ | 1314.771 | 12 | 76058.87 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 6d\ ^4G_{5\frac{1}{2}}$ |
| 1282.732 | 1 | 77958.61 | | 1314.847 | 12 | 76054.48 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 6d\ ^4F_{4\frac{1}{2}}$ |
| 1282.825 | 10 | 77952.96 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^2P_{1\frac{1}{2}}$ | 1315.255 | 70 | 76030.88 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 6d\ ^4H_{5\frac{1}{2}}$ |
| 1283.399 | 12 | 77918.09 | $4s\ ^4F_{1\frac{1}{2}} - z\ ^6F^\circ_{1\frac{1}{2}}$ | 1315.558 | 3 | 76013.37 | $4p\ ^4G^\circ_{2\frac{1}{2}} - 6d\ ^2D_{2\frac{1}{2}}$ |
| 1283.731 | 3 | 77897.94 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 7d\ ^4D_{2\frac{1}{2}}$ | 1316.502 | 4 | 75958.87 | $4p\ ^4D^\circ_{0\frac{1}{2}} - 7s\ ^4F_{1\frac{1}{2}}$ |
| 1284.327 | 25 | 77861.79 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 6d\ ^4F_{4\frac{1}{2}}$ | 1317.045 | 6 | 75927.55 | $4p\ ^4G^\circ_{5\frac{1}{2}} - 6d\ ^4G_{5\frac{1}{2}}$ |
| 1286.338 | 50 | 77740.06 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 6d\ ^4D_{3\frac{1}{2}}$ | 1317.122 | 10 | 75923.11 | $4p\ ^4G^\circ_{5\frac{1}{2}} - 6d\ ^4F_{4\frac{1}{2}}$ |
| 1286.396 | 3 | 77736.56 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 7s\ ^4F_{2\frac{1}{2}}$ | 1317.220 | 500 | 75917.46 | $3d\ ^2D_{2\frac{1}{2}} - 4p'''\ ^2F^\circ_{3\frac{1}{2}}$ |
| 1286.561 | 50 | 77726.59 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 6d\ ^4P_{2\frac{1}{2}}$ | 1317.531 | 15 | 75899.54 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 6d\ ^4H_{5\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 1318.017 | 100 | 75871.55 | $4p\ ^4G^\circ_{5/2} - 6d\ ^4H_{6/2}$ |
| 1319.310 | 8 | 75797.20 | $4p\ ^4G^\circ_{2/2} - 6d\ ^4G_{3/2}$ |
| 1320.799 | 0 | 75711.75 | $4p\ ^4G^\circ_{2/2} - 6d\ ^4F_{2/2}$ |
| 1321.432 | 3 | 75675.48 | $4p\ ^4F^\circ_{2/2} - 6d\ ^2G_{3/2}$ |
| 1321.704 | 2 | 75659.91 | $4p\ ^4D^\circ_{1/2} - 7s\ ^4F_{2/2}$ |
| 1322.825 | 2 | 75595.79 | $4p\ ^4F^\circ_{2/2} - 6d\ ^4G_{2/2}$ |
| 1323.107 | 1 | 75579.68 | $4p\ ^4G^\circ_{3/2} - 6d\ ^4D_{2/2}$ |
| 1323.417 | 25 | 75561.97 | $4p\ ^4F^\circ_{2/2} - 6d\ ^4H_{3/2}$ |
| 1324.475 | 25 | 75501.61 | $4p\ ^2G^\circ_{4/2} - 6d\ ^2G_{4/2}$ |
| 1325.105 | 1 | 75465.72 | $4p\ ^2G^\circ_{4/2} - 6d\ ^2F_{3/2}$ |
| 1325.242 | 1 | 75457.92 | $4p\ ^2G^\circ_{4/2} - 6d\ ^4H_{4/2}$ |
| 1325.359 | 100 | 75451.25 | $4p\ ^2G^\circ_{4/2} - 6d\ ^2H_{5/2}$ |
| 1325.691 | 4 | 75432.36 | $4s''\ ^2P_{1/2} - 5p\ ^4D^\circ_{2/2}$ |
| 1326.292 | 7 | 75398.18 | $4p\ ^4F^\circ_{3/2} - 6d\ ^4G_{3/2}$ |
| 1326.548 | 11 | 75383.63 | $4p\ ^4F^\circ_{3/2} - 6d\ ^2G_{4/2}$ |
| 1326.623 | 12 | 75379.37 | $4p\ ^2G^\circ_{3/2} - 6d\ ^2G_{3/2}$ |
| 1327.187 | 3 | 75347.33 | $4p\ ^2D^\circ_{1/2} - 5d'\ ^2D_{2/2}$ |
| 1327.319 | 20 | 75339.84 | $4p\ ^4F^\circ_{3/2} - 6d\ ^4H_{4/2}$ |
| 1327.730 | 8 | 75316.52 | $4p\ ^2F^\circ_{2/2} - 8s\ ^4F_{3/2}$ |
| 1327.755 | 50 | 75315.10 | $4p\ ^2G^\circ_{3/2} - 6d\ ^2H_{4/2}$ |
| 1328.847 | 3 | 75253.21 | $4p\ ^4D^\circ_{2/2} - 7s\ ^4F_{3/2}$ |
| 1328.964 | 25 | 75246.58 | $4p\ ^4F^\circ_{1/2} - 6d\ ^4G_{2/2}$ |
| 1329.857 | 13 | 75196.05 | $4p\ ^4F^\circ_{1/2} - 6d\ ^4F_{1/2}$ |
| 1331.264 | 9 | 75116.58 | $4p\ ^4G^\circ_{2/2} - 7s\ ^4F_{1/2}$ |
| 1332.706 | 1 | 75035.30 | $4p\ ^4G^\circ_{3/2} - 6d\ ^4D_{3/2}$ |
| 1332.766 | 6 | 75031.92 | $4p\ ^4G^\circ_{3/2} - 7s\ ^4F_{2/2}$ |
| 1332.808 | 7 | 75029.56 | $4p\ ^2D^\circ_{1/2} - 5d'\ ^2F_{2/2}$ |
| 1333.171 | 3 | 75009.13 | $4p\ ^4G^\circ_{3/2} - 7s\ ^2F_{3/2}$ |
| 1334.101 | 10 | 74956.84 | $4p\ ^4F^\circ_{2/2} - 6d\ ^2D_{2/2}$ |
| 1334.287 | 12 | 74946.39 | $4p\ ^4F^\circ_{4/2} - 6d\ ^4G_{4/2}$ |
| 1334.320 | 7 | 74944.54 | |
| 1334.656 | 1 | 74925.67 | |
| 1334.689 | 1 | 74923.82 | |
| 1335.203 | 400 | 74894.98 | $3d\ ^2D_{1/2} - 4p'''\ ^2F^\circ_{2/2}$ |
| 1335.779 | 18 | 74862.68 | $4p\ ^4F^\circ_{4/2} - 6d\ ^4F_{4/2}$ |
| 1336.201 | 2 | 74839.04 | $4p\ ^4F^\circ_{4/2} - 6d\ ^4H_{5/2}$ |
| 1337.958 | 15 | 74740.76 | $4p\ ^4F^\circ_{4/2} - 6d\ ^4D_{3/2}$ |
| | | | $4p\ ^4F^\circ_{2/2} - 6d\ ^4G_{3/2}$ |
| 1338.195 | 10 | 74727.52 | |
| 1338.402 | 1 | 74715.97 | $4p\ ^2F^\circ_{3/2} - 6d\ ^2F_{2/2}$ |
| 1339.221 | 3 | 74670.27 | $4p\ ^2F^\circ_{3/2} - 6d\ ^2G_{3/2}$ |
| 1339.394 | 1 | 74660.63 | $4p\ ^2G^\circ_{3/2} - 6d\ ^2D_{2/2}$ |
| 1339.487 | 3 | 74655.45 | $4p\ ^4F^\circ_{2/2} - 6d\ ^4F_{2/2}$ |
| 1340.007 | 15 | 74626.48 | $4p\ ^4G^\circ_{4/2} - 7s\ ^4F_{3/2}$ |
| 1340.374 | 20 | 74606.04 | $4p\ ^2F^\circ_{3/2} - 6d\ ^2H_{4/2}$ |
| 1341.226 | 00 | 74558.65 | $4s'''\ ^2G_{3/2} - 5p\ ^2F^\circ_{2/2}$ |
| 1342.242 | 20 | 74502.21 | $4p\ ^4G^\circ_{4/2} - 7s\ ^4F_{4/2}$ |
| 1343.544 | 10 | 74430.01 | $4p\ ^2G^\circ_{3/2} - 6d\ ^2G_{4/2}$ |
| 1343.642 | 2 | 74424.59 | $4p\ ^4F^\circ_{3/2} - 6d\ ^4D_{2/2}$ |
| 1344.196 | 2 | 74393.91 | $4p\ ^2G^\circ_{3/2} - 6d\ ^2F_{3/2}$ |
| 1344.334 | 1 | 74386.28 | $4p\ ^2G^\circ_{3/2} - 6d\ ^4H_{4/2}$ |
| 1344.614 | 50 | 74370.79 | $4p\ ^4G^\circ_{5/2} - 7s\ ^4F_{4/2}$ |
| 1345.882 | 50 | 74300.72 | $3d\ ^2D_{2/2} - 4p''\ ^4S^\circ_{1/2}$ |
| 1346.334 | 1 | 74275.77 | $4p\ ^4G^\circ_{2/2} - 7s\ ^4F_{2/2}$ |
| 1348.333 | 30 | 74165.65 | $4s'\ ^2D_{2/2} - z\ ^4D^\circ_{2/2}$ |
| 1349.594 | 00 | 74096.36 | $4p\ ^2G^\circ_{4/2} - 6d\ ^4H_{5/2}$ |
| 1349.791 | 12 | 74085.54 | $4p\ ^4F^\circ_{3/2} - 6d\ ^4G_{4/2}$ |
| 1350.256 | 5 | 74060.03 | $4p\ ^4F^\circ_{2/2} - 7s\ ^4F_{1/2}$ |
| 1350.321 | 10 | 74056.46 | $4p\ ^4F^\circ_{3/2} - 6d\ ^4F_{3/2}$ |
| 1351.287 | 10 | 74003.52 | $4s'\ ^2D_{1/2} - z\ ^4D^\circ_{2/2}$ |
| 1351.862 | 35 | 73972.05 | $4p\ ^2G^\circ_{4/2} - 7s\ ^2F_{3/2}$ |
| 1352.237 | 10 | 73951.53 | $4p\ ^2F^\circ_{3/2} - 6d\ ^2D_{2/2}$ |
| 1353.606 | 8 | 73876.74 | $4p\ ^4F^\circ_{2/2} - 7s\ ^4F_{2/2}$ |
| 1353.821 | 15 | 73865.01 | $4p\ ^2G^\circ_{3/2} - 7s\ ^2F_{2/2}$ |
| 1354.023 | 2 | 73853.99 | $4p\ ^4F^\circ_{3/2} - 7s\ ^2F_{3/2}$ |
| 1355.849 | 10 | 73754.53 | |
| 1356.318 | 5 | 73729.02 | $4p\ ^4G^\circ_{3/2} - 7s\ ^4F_{3/2}$ |
| 1356.469 | 20 | 73720.81 | $4p\ ^2F^\circ_{3/2} - 6d\ ^2G_{4/2}$ |
| 1356.653 | 9 | 73710.82 | $4p\ ^4F^\circ_{1/2} - 7s\ ^4F_{1/2}$ |
| 1357.132 | 11 | 73684.80 | $4p\ ^2F^\circ_{3/2} - 6d\ ^2F_{3/2}$ |
| 1357.371 | 5 | 73671.83 | $4s''\ ^2P_{1/2} - z\ ^2D^\circ_{1/2}$ |
| 1358.475 | 25 | 73611.95 | $4p\ ^2D^\circ_{2/2} - 6d\ ^2D_{2/2}$ |
| 1358.992 | 15 | 73583.95 | |
| 1360.956 | 14 | 73477.76 | $4s'\ ^2D_{1/2} - z\ ^4D^\circ_{2/2}$ |
| 1361.757 | 5 | 73434.54 | $4p\ ^4F^\circ_{4/2} - 7s\ ^4F_{3/2}$ |
| 1361.885 | 50 | 73427.64 | $4s'\ ^2D_{2/2} - z\ ^4D^\circ_{3/2}$ |
| 1362.926 | 20 | 73371.55 | |
| 1363.421 | 3h | 73344.92 | $4p\ ^2D^\circ_{2/2} - 6d\ ^2F_{3/2}$ |
| 1363.540 | 2 | 73338.52 | $4s'''\ ^2G_{4/2} - 5p\ ^2F^\circ_{3/2}$ |
| 1363.617 | 2 | 73334.37 | $4s''\ ^4P_{1/2} - z\ ^4D^\circ_{0/2}$ |
| 1363.861 | 1 | 73321.25 | |
| 1364.067 | 25 | 73310.18 | $4p\ ^4F^\circ_{4/2} - 7s\ ^4F_{4/2}$ |
| 1364.202 | 25 | 73302.93 | $4p\ ^2F^\circ_{2/2} - 6d\ ^2F_{2/2}$ |
| 1364.440 | 1 | 73290.14 | |
| 1364.505 | 20 | 73286.65 | $4s''\ ^4P_{0/2} - z\ ^4D^\circ_{0/2}$ |
| 1364.793 | 2 | 73271.18 | $4p\ ^2D^\circ_{2/2} - 6d\ ^2P_{1/2}$ |
| 1365.048 | 25 | 73257.50 | $4p\ ^2F^\circ_{2/2} - 6d\ ^2G_{3/2}$ |
| 1365.760 | 4 | 73219.31 | $4p\ ^4F^\circ_{2/2} - 7s\ ^4F_{2/2}$ |
| 1366.947 | 5 | 73155.72 | $4p\ ^2F^\circ_{3/2} - 7s\ ^2F_{2/2}$ |
| 1367.067 | 20 | 73149.30 | $4s''\ ^2P_{0/2} - z\ ^2D^\circ_{1/2}$ |
| 1367.394 | 1 | 73131.81 | $4p\ ^2G^\circ_{3/2} - 6d\ ^4G_{4/2}$ |
| 1368.171 | 10 | 73090.28 | $4p\ ^2D^\circ_{1/2} - 6d\ ^2F_{2/2}$ |
| 1369.560 | 1 | 73016.15 | |
| 1369.651 | 20 | 73011.30 | $4s''\ ^4P_{1/2} - z\ ^4D^\circ_{1/2}$ |
| 1370.136 | 500 | 72985.46 | $3d\ ^2D_{2/2} - 4p''\ ^2P^\circ_{1/2}$ |
| 1370.549 | 25 | 72963.46 | $4s''\ ^4P_{0/2} - z\ ^4D^\circ_{1/2}$ |
| 1370.804 | 4 | 72949.89 | $4p\ ^2D^\circ_{1/2} - 6d\ ^2P_{0/2}$ |
| 1371.733 | 1 | 72900.48 | $4p\ ^2G^\circ_{3/2} - 7s\ ^2F_{3/2}$ |
| 1373.746 | 4 | 72793.66 | $3d\ ^2D_{1/2} - 4p''\ ^4S^\circ_{1/2}$ |
| 1374.075 | 150 | 72776.23 | $3d\ ^2D_{1/2} - 4p''\ ^2S^\circ_{0/2}$ |
| 1375.822 | 50 | 72683.82 | $4s''\ ^2P_{1/2} - z\ ^2D^\circ_{2/2}$ |
| 1377.001 | 10 | 72621.59 | |
| 1377.912 | 7 | 72573.57 | $4p\ ^4F^\circ_{3/2} - 7s\ ^4F_{3/2}$ |
| 1378.578 | 1 | 72538.51 | $4p\ ^2F^\circ_{2/2} - 6d\ ^2D_{2/2}$ |
| 1379.586 | 50 | 72485.51 | $4s''\ ^4P_{1/2} - z\ ^4D^\circ_{2/2}$ |
| 1379.980 | 12 | 72464.82 | $4s'\ ^2D_{2/2} - z\ ^4G^\circ_{3/2}$ |
| 1380.440 | 2 | 72440.67 | |
| 1380.793 | 20 | 72422.15 | $4p\ ^2D^\circ_{2/2} - 6d\ ^4D_{2/2}$ |
| 1381.295 | 200 | 72395.83 | $3d\ ^2D_{1/2} - 4p''\ ^2P^\circ_{0/2}$ |
| 1381.423 | 6 | 72389.12 | $s^2\ ^4F_{4/2} - 6p\ ^2G^\circ_{4/2}$ |
| 1381.694 | 4 | 72374.92 | $3d\ ^2D_{2/2} - 4p''\ ^2D^\circ_{1/2}$ |
| 1382.695 | 2 | 72322.53 | $4p\ ^2F^\circ_{2/2} - 6d\ ^4G_{3/2}$ |
| 1383.356 | 1 | 72287.97 | |
| 1383.966 | 00 | 72256.11 | $4s'\ ^2D_{1/2} - 4p\ ^4G^\circ_{2/2}$ |
| 1384.327 | 12 | 72237.27 | $4p\ ^2F^\circ_{2/2} - 6d\ ^4F_{2/2}$ |
| | | | $4s''\ ^4P_{2/2} - z\ ^4D^\circ_{2/2}$ |
| 1385.179 | 1 | 72192.83 | |
| 1385.216 | 6 | 72190.91 | $4p\ ^2F^\circ_{3/2} - 7s\ ^2F_{3/2}$ |
| 1386.063 | 1 | 72146.79 | $4s'''\ ^2G_{4/2} - 5p\ ^4F^\circ_{3/2}$ |
| 1387.745 | 10 | 72059.35 | $4p\ ^2D^\circ_{2/2} - 6d\ ^4P_{1/2}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 1387.851 | 5 | 72053.84 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 6d\ ^4F_{3\frac{1}{2}}$ |
| 1388.796 | 1 | 72004.81 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 6d\ ^4P_{0\frac{1}{2}}$ |
| 1391.761 | 2 | 71851.42 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 7s\ ^2F_{3\frac{1}{2}}$ |
| 1393.330 | 100 | 71770.51 | $3d\ ^2D_{2\frac{1}{2}} - 4p''\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1393.867 | 12 | 71742.86 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 7s\ ^2F_{2\frac{1}{2}}$ |
| 1396.695 | 10 | 71597.59 | $4s'\ ^2D_{2\frac{1}{2}} - z\ ^4F^\circ_{3\frac{1}{2}}$ |
| 1396.790 | 14 | 71592.72 | |
| 1397.480 | 2 | 71557.37 | $4s'''\ ^2G_{3\frac{1}{2}} - 5p\ ^4G^\circ_{4\frac{1}{2}}$ |
| 1397.858 | 2 | 71538.02 | $4s''\ ^2P_{1\frac{1}{2}} - z\ ^2F^\circ_{2\frac{1}{2}}$ |
| 1398.009 | 3 | 71530.30 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 7s\ ^2F_{2\frac{1}{2}}$ |
| 1398.612 | 40 | 71499.46 | $4s''\ ^4P_{2\frac{1}{2}} - z\ ^4D^\circ_{3\frac{1}{2}}$ |
| 1398.758 | 16 | 71492.00 | |
| 1399.026 | 80 | 71478.30 | $3d\ ^2D_{1\frac{1}{2}} - 4p''\ ^2P^\circ_{1\frac{1}{2}}$ |
| 1399.361 | 12 | 71461.19 | |
| 1400.644 | 30 | 71395.73 | $s^2\ ^4F_{4\frac{1}{2}} - 6p\ ^4F^\circ_{4\frac{1}{2}}$ |
| 1402.379 | 20 | 71307.40 | |
| 1406.970 | 7 | 71074.72 | $s^2\ ^4F_{4\frac{1}{2}} - 6p\ ^4G^\circ_{5\frac{1}{2}}$ |
| 1408.796 | 10 | 70982.60 | |
| 1409.612 | 15 | 70941.51 | |
| 1410.219 | 4 | 70910.97 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 7s\ ^4F_{3\frac{1}{2}}$ |
| 1411.071 | 100 | 70868.16 | $3d\ ^2D_{1\frac{1}{2}} - 4p''\ ^2D^\circ_{1\frac{1}{2}}$ |
| 1412.868 | 30 | 70778.02 | $3d\ ^2D_{2\frac{1}{2}} - 4p''\ ^4D^\circ_{3\frac{1}{2}}$ |
| 1413.679 | 10 | 70737.42 | |
| 1414.299 | 15 | 70706.41 | $3d\ ^2D_{2\frac{1}{2}} - 4p''\ ^4D^\circ_{1\frac{1}{2}}$ |
| 1414.444 | 1 | 70699.16 | |
| 1415.728 | 20 | 70635.04 | $3d\ ^2D_{2\frac{1}{2}} - 4p''\ ^4D^\circ_{2\frac{1}{2}}$ |
| 1415.846 | 1 | 70629.15 | |
| 1416.060 | 12 | 70618.48 | |
| 1416.660 | 0 | 70588.57 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 7s\ ^4F_{2\frac{1}{2}}$ |
| 1417.007 | 10 | 70571.28 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 7s\ ^4F_{3\frac{1}{2}}$ |
| 1417.553 | 1 | 70544.10 | $4s''\ ^4P_{1\frac{1}{2}} - z\ ^4F^\circ_{2\frac{1}{2}}$ |
| 1417.699 | 10 | 70536.83 | $4s''\ ^4P_{2\frac{1}{2}} - z\ ^4G^\circ_{3\frac{1}{2}}$ |
| 1420.674 | 5 | 70389.12 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 5d''\ ^4P_{2\frac{1}{2}}$ |
| 1420.843 | 18 | 70380.75 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 5d''\ ^4P_{2\frac{1}{2}}$ |
| 1421.913 | 1 | 70327.79 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 5d''\ ^4P_{1\frac{1}{2}}$ |
| 1422.320 | 8 | 70307.67 | |
| 1423.212 | 16 | 70263.60 | $3d\ ^2D_{1\frac{1}{2}} - 4p''\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1423.786 | 11 | 70235.27 | $s^2\ ^4F_{3\frac{1}{2}} - 6p\ ^4F^\circ_{4\frac{1}{2}}$ |
| 1423.994 | 1 | 70225.01 | |
| 1424.890 | 3 | 70180.86 | $4p''\ ^4P^\circ_{0\frac{1}{2}} - 5d''\ ^4P_{0\frac{1}{2}}$ |
| 1425.025 | 10 | 70174.21 | |
| 1425.579 | 6 | 70146.94 | |
| 1425.604 | 3 | 70145.71 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 5d''\ ^4P_{0\frac{1}{2}}$ |
| 1426.783 | 5 | 70087.74 | |
| 1427.448 | 1 | 70055.09 | |
| 1427.782 | 10 | 70038.70 | |
| 1431.270 | 8 | 69868.02 | $4p''\ ^4P^\circ_{0\frac{1}{2}} - 5d''\ ^4P_{1\frac{1}{2}}$ |
| 1431.492 | 25 | 69857.18 | $s^2\ ^4F_{4\frac{1}{2}} - 5p''\ ^4D^\circ_{3\frac{1}{2}}$ |
| 1433.745 | 1 | 69747.41 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 5d''\ ^4D_{1\frac{1}{2}}$ |
| 1433.893 | 1 | 69740.21 | |
| 1434.317 | 1 | 69719.59 | |
| 1434.373 | 12 | 69716.87 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 5d''\ ^4D_{2\frac{1}{2}}$ |
| 1434.493 | 14 | 69711.04 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 5d''\ ^4D_{0\frac{1}{2}}$? |
| 1434.546 | 12 | 69708.46 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 5d''\ ^4D_{2\frac{1}{2}}$ |
| 1434.688 | 1 | 69701.57 | $4p''\ ^4P^\circ_{0\frac{1}{2}} - 5d''\ ^4F_{1\frac{1}{2}}$ |
| 1434.837 | 1 | 69694.33 | $4p''\ ^4P^\circ_{0\frac{1}{2}} - 5d''\ ^4P_{0\frac{1}{2}}$ |
| 1435.348 | 5 | 69669.51 | $4s\ ^4P_{2\frac{1}{2}} - z\ ^4F^\circ_{3\frac{1}{2}}$ |
| 1436.165 | 50 | 69629.88 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 5d''\ ^4D_{3\frac{1}{2}}$ |
| 1439.094 | 8 | 69488.16 | |
| 1439.283 | 1 | 69479.04 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 8s\ ^2F_{2\frac{1}{2}}$ |
| 1439.352 | 8 | 69475.71 | |
| 1443.080 | 13 | 69296.23 | $4p''\ ^4P^\circ_{0\frac{1}{2}} - 5d''\ ^4D_{1\frac{1}{2}}$ |
| 1443.838 | 10 | 69259.85 | $4p''\ ^4P^\circ_{0\frac{1}{2}} - 5d''\ ^4D_{0\frac{1}{2}}$ |
| 1444.940 | 1 | 69207.03 | |
| 1445.098 | 13 | 69199.46 | $3d\ ^2D_{1\frac{1}{2}} - 4p''\ ^4D^\circ_{1\frac{1}{2}}$ |
| 1445.460 | 14 | 69182.13 | |
| 1446.589 | 20 | 69128.13 | $3d\ ^2D_{1\frac{1}{2}} - 4p''\ ^4D^\circ_{2\frac{1}{2}}$ |
| 1450.005 | 14 | 68965.28 | $3d\ ^2D_{2\frac{1}{2}} - 4p'\ ^2P^\circ_{1\frac{1}{2}}$ |
| 1452.558 | 15 | 68844.07 | |
| 1453.359 | 15 | 68806.12 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 5d''\ ^4P_{2\frac{1}{2}}$ |
| 1454.292 | 2 | 68761.98 | $s^2\ ^4F_{2\frac{1}{2}} - 5p''\ ^2D^\circ_{1\frac{1}{2}}$ |
| 1454.852 | 200 | 68735.51 | $3d\ ^2D_{2\frac{1}{2}} - 4p'\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1456.913 | 16 | 68638.28 | |
| 1457.359 | 5 | 68617.27 | |
| 1457.863 | 4 | 68593.55 | $4p'\ ^2F^\circ_{2\frac{1}{2}} - 5d''\ ^4D_{2\frac{1}{2}}$ |
| 1458.170 | 4 | 68579.11 | $4p'\ ^4D^\circ_{2\frac{1}{2}} - 5d\ ^4G_{3\frac{1}{2}}$ |
| 1458.342 | 4 | 68571.02 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 5d''\ ^4P_{0\frac{1}{2}}$ |
| 1459.459 | 4 | 68518.54 | |
| 1459.611 | 1 | 68511.40 | |
| 1459.640 | 1 | 68510.04 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 5d\ ^4G_{2\frac{1}{2}}$ |
| 1459.715 | 12 | 68506.52 | $4p'\ ^2F^\circ_{2\frac{1}{2}} - 5d''\ ^4D_{3\frac{1}{2}}$ |
| 1459.809 | 9 | 68502.11 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 5d\ ^2F_{3\frac{1}{2}}$ |
| 1460.078 | 6 | 68489.49 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 5d\ ^4F_{2\frac{1}{2}}$ |
| 1460.136 | 1 | 68486.77 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 5d\ ^4G_{4\frac{1}{2}}$ |
| 1460.312 | 1 | 68478.52 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 5d\ ^2P_{0\frac{1}{2}}$ |
| 1460.408 | 2 | 68474.01 | |
| 1461.840 | 8 | 68406.94 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 7d\ ^4D_{2\frac{1}{2}}$ |
| 1462.482 | 8 | 68376.91 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 5d\ ^2P_{1\frac{1}{2}}$ |
| 1462.944 | 20 | 68355.32 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 5d\ ^4F_{4\frac{1}{2}}$ |
| 1463.113 | 14 | 68347.42 | $s^2\ ^4F_{2\frac{1}{2}} - 5p''\ ^4D^\circ_{1\frac{1}{2}}$ |
| 1464.301 | 8 | 68291.97 | |
| 1464.369 | 10 | 68288.80 | |
| 1467.265 | 60 | 68154.01 | $3d\ ^2D_{2\frac{1}{2}} - 4p'\ ^2D^\circ_{1\frac{1}{2}}$ |
| 1467.637 | 10 | 68136.74 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 5d''\ ^4D_{0\frac{1}{2}}$ |
| | | | $s^2\ ^2G_{4\frac{1}{2}} - w\ ^2G^\circ_{4\frac{1}{2}}$? |
| 1467.694 | 10 | 68134.09 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 5d''\ ^4D_{2\frac{1}{2}}$ |
| 1467.762 | 100 | 68130.94 | $3d\ ^2D_{2\frac{1}{2}} - 4p'\ ^2F^\circ_{3\frac{1}{2}}$ |
| 1468.268 | 30 | 68107.46 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 5d\ ^4P_{2\frac{1}{2}}$ |
| 1468.465 | 25 | 68098.32 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 5d\ ^4D_{3\frac{1}{2}}$ |
| 1469.200 | 10 | 68064.25 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 5d\ ^4D_{1\frac{1}{2}}$ |
| 1469.601 | 3 | 68045.68 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 5d''\ ^4D_{1\frac{1}{2}}$ |
| 1469.847 | 1 | 68034.29 | |
| 1470.322 | 1 | 68012.31 | $s^2\ ^4F_{2\frac{1}{2}} - 5p''\ ^4D^\circ_{2\frac{1}{2}}$ |
| 1470.386 | 2 | 68009.35 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 5d''\ ^4D_{0\frac{1}{2}}$ |
| 1470.666 | 5 | 67996.40 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 5d''\ ^4F_{1\frac{1}{2}}$ |
| 1471.466 | 10 | 67959.44 | $s^2\ ^4F_{1\frac{1}{2}} - 5p''\ ^4D^\circ_{0\frac{1}{2}}$ |
| 1471.961 | 1 | 67936.58 | $4p\ ^4D^\circ_{0\frac{1}{2}} - 5d\ ^2P_{0\frac{1}{2}}$ |
| 1472.571 | 10 | 67908.44 | $4p\ ^4D^\circ_{0\frac{1}{2}} - 5d\ ^4F_{1\frac{1}{2}}$ |
| 1472.835 | 5 | 67896.27 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 8s\ ^2F_{2\frac{1}{2}}$ |
| 1472.889 | 2 | 67893.78 | $s^2\ ^4F_{4\frac{1}{2}} - 4f\ ^4G^\circ_{5\frac{1}{2}}$? |
| 1473.249 | 1 | 67877.19 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 7d\ ^2D_{2\frac{1}{2}}$ |
| 1474.312 | 1 | 67828.25 | |
| 1474.597 | 4 | 67815.14 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 5d\ ^2H_{5\frac{1}{2}}$ |
| 1474.901 | 2 | 67801.16 | |
| 1474.910 | 1 | 67800.75 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 5d''\ ^4F_{2\frac{1}{2}}$ |
| 1475.270 | 3 | 67784.20 | $s^2\ ^4F_{1\frac{1}{2}} - 5p''\ ^4D^\circ_{1\frac{1}{2}}$? |
| 1475.645 | 1 | 67766.98 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 5d''\ ^4F_{1\frac{1}{2}}$ |
| 1475.734 | 3 | 67762.89 | $s^2\ ^2G_{4\frac{1}{2}} - 9p\ ^4F^\circ_{4\frac{1}{2}}$ |
| 1475.801 | 2 | 67759.81 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 5d''\ ^4P_{0\frac{1}{2}}$ |
| 1476.043 | 25 | 67748.70 | $4p\ ^4D^\circ_{0\frac{1}{2}} - 5d\ ^4D_{0\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 1477.063 | 1 | 67701.92 | $4p'\ ^2P^\circ_{0\,1/2} - 8s\ ^4F_{1\,1/2}$ |
| 1477.227 | 4 | 67694.40 | $3d\ ^2D_{2\,1/2} - 4p'\ ^2F^\circ_{2\,1/2}$ |
| 1477.264 | 1 | 67692.71 | $s^2\ ^4P_{1\,1/2} - 4f''\ ^4D^\circ_{2\,1/2}$ |
| 1479.443 | 10 | 67593.01 | $4p\ ^4D^\circ_{1\,1/2} - 5d\ ^4F_{2\,1/2}$ |
| 1480.274 | 4 | 67555.06 | |
| 1480.331 | 30 | 67552.46 | $4p'\ ^2D^\circ_{2\,1/2} - 5d''\ ^4D_{2\,1/2}$ |
| 1481.091 | 75 | 67517.79 | $s^2\ ^4F_{4\,1/2} - 5p'\ ^2F^\circ_{3\,1/2}$ |
| 1481.210 | 9 | 67512.37 | |
| 1481.560 | 15 | 67496.42 | $4p''\ ^4P^\circ_{2\,1/2} - 5d'\ ^2P_{1\,1/2}$ |
| | | | $s^2\ ^4P_{1\,1/2} - 4f''\ ^4D^\circ_{1\,1/2}$ |
| 1481.744 | 15 | 67488.04 | $4p''\ ^4P^\circ_{1\,1/2} - 5d'\ ^2P_{1\,1/2}$ |
| 1481.883 | 12 | 67481.71 | $4p''\ ^4P^\circ_{2\,1/2} - 5d'\ ^2D_{2\,1/2}$ |
| 1481.898 | 4 | 67481.03 | $4p\ ^4D^\circ_{1\,1/2} - 5d\ ^2P_{1\,1/2}$ |
| 1481.982 | 10 | 67477.20 | $4p\ ^4D^\circ_{1\,1/2} - 5d\ ^4P_{0\,1/2}$ |
| 1482.240 | 100 | 67465.46 | $4p'\ ^2D^\circ_{2\,1/2} - 5d''\ ^4D_{3\,1/2}$ |
| 1482.393 | 8 | 67458.49 | $3d\ ^2D_{1\,1/2} - 4p'\ ^2P^\circ_{1\,1/2}$ |
| 1483.277 | 40 | 67418.29 | |
| 1483.554 | 15 | 67405.70 | $4p\ ^4D^\circ_{2\,1/2} - 5d\ ^4D_{2\,1/2}$ |
| 1483.760 | 1 | 67396.34 | |
| 1484.227 | 25 | 67375.14 | $4p''\ ^4P^\circ_{1\,1/2} - 5d'\ ^2P_{0\,1/2}$ |
| 1484.592 | 1 | 67358.57 | $4p''\ ^4P^\circ_{2\,1/2} - 5d'\ ^2G_{3\,1/2}$ |
| 1485.185 | 10 | 67331.68 | $4p''\ ^4P^\circ_{2\,1/2} - 5d'\ ^2D_{1\,1/2}$ |
| 1485.375 | 60 | 67323.07 | $4p'\ ^2P^\circ_{1\,1/2} - 5d''\ ^4D_{2\,1/2}$ |
| 1485.987 | 2 | 67295.34 | $4p'\ ^2D^\circ_{2\,1/2} - 7d\ ^2D_{2\,1/2}$ |
| 1486.372 | 5 | 67277.91 | $4p''\ ^4P^\circ_{1\,1/2} - 6s''\ ^4P_{0\,1/2}$ |
| 1486.668 | 7 | 67264.51 | $4p\ ^4D^\circ_{2\,1/2} - 5d\ ^4F_{3\,1/2}$ |
| 1487.242 | 50 | 67238.55 | $4p''\ ^4P^\circ_{2\,1/2} - 8s\ ^4F_{3\,1/2}$ |
| 1487.438 | 5 | 67229.69 | |
| 1487.455 | 6 | 67228.92 | $3d\ ^2D_{1\,1/2} - 4p'\ ^2D^\circ_{2\,1/2}$ |
| 1487.778 | 5 | 67214.33 | |
| 1487.970 | 2 | 67205.66 | |
| 1488.109 | 1 | 67199.38 | |
| 1488.730 | 16 | 67171.35 | $4p\ ^4D^\circ_{2\,1/2} - 5d\ ^4P_{1\,1/2}$ |
| 1488.845 | 5 | 67166.16 | $4p'\ ^2D^\circ_{2\,1/2} - 7d\ ^4F_{2\,1/2}$ |
| 1488.896 | 100 | 67163.86 | $4p''\ ^4P^\circ_{2\,1/2} - 5d'\ ^2F_{2\,1/2}$ |
| 1489.079 | 35 | 67155.60 | $4p''\ ^4P^\circ_{1\,1/2} - 5d'\ ^2F_{2\,1/2}$ |
| 1489.729 | 5 | 67126.30 | $4p\ ^4G^\circ_{2\,1/2} - 5d\ ^4G_{2\,1/2}$ |
| 1490.262 | 7 | 67102.29 | $s^2\ ^4P_{1\,1/2} - v\ ^2D^\circ_{2\,1/2}$ |
| 1491.176 | 5 | 67061.17 | |
| 1491.308 | 4 | 67055.23 | $4p\ ^4G^\circ_{3\,1/2} - 5d\ ^4G_{3\,1/2}$ |
| 1491.588 | 4 | 67042.64 | $4p''\ ^4P^\circ_{2\,1/2} - 6s''\ ^4P_{1\,1/2}$ |
| 1491.776 | 6 | 67034.19 | $4p''\ ^4P^\circ_{1\,1/2} - 6s''\ ^4P_{1\,1/2}$ |
| 1491.823 | 3 | 67032.08 | $4p\ ^4G^\circ_{3\,1/2} - 5d\ ^2G_{4\,1/2}$ |
| 1491.899 | 40 | 67028.67 | $4p\ ^4G^\circ_{2\,1/2} - 5d\ ^4H_{3\,1/2}$ |
| 1493.022 | 15 | 66978.25 | $4p\ ^4G^\circ_{3\,1/2} - 5d\ ^2F_{3\,1/2}$ |
| 1493.315 | 2 | 66965.11 | $4p\ ^4G^\circ_{3\,1/2} - 5d\ ^4F_{2\,1/2}$ |
| 1494.151 | 50 | 66927.64 | $4p\ ^4G^\circ_{3\,1/2} - 5d\ ^4H_{4\,1/2}$ |
| 1494.236 | 6 | 66923.83 | $4p''\ ^4P^\circ_{0\,1/2} - 5d'\ ^2P_{0\,1/2}$ |
| 1494.701 | 10 | 66903.01 | $s^2\ ^4P_{2\,1/2} - w\ ^2D^\circ_{2\,1/2}$ |
| 1495.383 | 40 | 66872.50 | $4p''\ ^4P^\circ_{2\,1/2} - 6s''\ ^4P_{2\,1/2}$ |
| 1495.570 | 20 | 66864.14 | $4p''\ ^4P^\circ_{1\,1/2} - 6s''\ ^4P_{2\,1/2}$ |
| 1496.308 | 10 | 66831.16 | $4p''\ ^4P^\circ_{0\,1/2} - 6s''\ ^2P_{1\,1/2}$ |
| 1496.409 | 2 | 66826.65 | $4p''\ ^4P^\circ_{0\,1/2} - 6s''\ ^4P_{0\,1/2}$ |
| 1496.463 | 1 | 66824.24 | $4p'\ ^2D^\circ_{1\,1/2} - 7d\ ^4D_{2\,1/2}$ |
| 1498.734 | 1 | 66722.98 | $4p\ ^4F^\circ_{3\,1/2} - 5d\ ^2H_{4\,1/2}$ |
| 1499.704 | 15 | 66679.82 | $4p\ ^4G^\circ_{4\,1/2} - 5d\ ^4G_{4\,1/2}$ |
| 1500.437 | 200 | 66647.25 | $3d\ ^2D_{1\,1/2} - 4p'\ ^2D^\circ_{1\,1/2}$ |
| 1500.651 | 7 | 66637.75 | $4p\ ^4G^\circ_{4\,1/2} - 5d\ ^4F_{3\,1/2}$ |
| 1501.885 | 20 | 66582.99 | $4p''\ ^4P^\circ_{0\,1/2} - 4s''\ ^4P_{1\,1/2}$ |
| 1501.962 | 6 | 66579.58 | $3d\ ^2D_{2\,1/2} - 4p''\ ^4P^\circ_{1\,1/2}$ |
| 1502.150 | 75 | 66571.25 | $3d\ ^2D_{2\,1/2} - 4p''\ ^4P^\circ_{2\,1/2}$ |
| 1502.669 | 20 | 66548.25 | $4p\ ^4G^\circ_{4\,1/2} - 5d\ ^4F_{4\,1/2}$ |
| 1503.123 | 7 | 66528.15 | $s^2\ ^4F_{4\,1/2} - w\ ^4F^\circ_{4\,1/2}$ |
| 1503.209 | 12 | 66524.35 | $4p\ ^4G^\circ_{4\,1/2} - 5d\ ^4G_{5\,1/2}$ |
| 1504.485 | 75 | 66467.93 | $4p\ ^4G^\circ_{4\,1/2} - 5d\ ^4H_{5\,1/2}$ |
| 1504.590 | 5 | 66463.29 | $4p''\ ^4D^\circ_{0\,1/2} - 5d''\ ^2P_{0\,1/2}$ |
| 1505.642 | 13 | 66416.85 | $4p\ ^4G^\circ_{5\,1/2} - 5d\ ^4F_{4\,1/2}$ |
| 1506.184 | 16 | 66392.95 | $4p\ ^4G^\circ_{5\,1/2} - 5d\ ^4G_{5\,1/2}$ |
| 1506.585 | 25 | 66375.28 | |
| 1506.851 | 7 | 66363.56 | |
| 1506.968 | 10 | 66358.41 | |
| 1506.995 | 5 | 66357.22 | $s^2\ ^4F_{3\,1/2} - 5p'\ ^2F^\circ_{3\,1/2}$ |
| 1507.465 | 18 | 66336.53 | $4p\ ^4G^\circ_{5\,1/2} - 5d\ ^4H_{5\,1/2}$ |
| 1507.961 | 15 | 66314.71 | $s^2\ ^2G_{4\,1/2} - 8p\ ^2G^\circ_{4\,1/2}$ |
| 1508.249 | 10 | 66302.05 | |
| 1508.262 | 7 | 66301.48 | $4p''\ ^4D^\circ_{2\,1/2} - 7d\ ^2G_{3\,1/2}$ |
| 1508.315 | 10 | 66299.15 | $4p\ ^4G^\circ_{2\,1/2} - 5d\ ^4G_{3\,1/2}$ |
| 1508.352 | 7 | 66297.52 | |
| 1508.498 | 4 | 66291.10 | $4p\ ^4G^\circ_{4\,1/2} - 5d\ ^4D_{3\,1/2}$ |
| 1508.816 | 100 | 66277.13 | $4p\ ^4G^\circ_{5\,1/2} - 5d\ ^4H_{6\,1/2}$ |
| 1509.113 | 1 | 66264.09 | $4p''\ ^4D^\circ_{2\,1/2} - 5d''\ ^4P_{1\,1/2}$ |
| 1509.308 | 12 | 66255.53 | |
| 1509.345 | 8 | 66253.90 | $4p''\ ^4D^\circ_{1\,1/2} - 5d''\ ^4P_{2\,1/2}$ |
| 1509.602 | 4 | 66242.62 | $4p'\ ^2D^\circ_{2\,1/2} - 7d\ ^4D_{2\,1/2}$ |
| 1509.767 | 100 | 66235.39 | $4p'\ ^2F^\circ_{2\,1/2} - 5d'\ ^2G_{3\,1/2}$ |
| 1510.067 | 1 | 66222.23 | $4p\ ^4G^\circ_{2\,1/2} - 5d\ ^2F_{3\,1/2}$ |
| 1510.232 | 16 | 66214.99 | |
| 1510.366 | 4 | 66209.12 | $4p\ ^4G^\circ_{2\,1/2} - 5d\ ^4F_{2\,1/2}$ |
| 1510.690 | 3 | 66194.92 | $4p\ ^4F^\circ_{2\,1/2} - 5d\ ^2G_{3\,1/2}$ |
| 1510.741 | 5 | 66192.68 | $4p''\ ^4D^\circ_{1\,1/2} - 5d''\ ^4P_{1\,1/2}$ |
| 1510.859 | 75 | 66187.51 | $3d\ ^2D_{1\,1/2} - 4p'\ ^2F^\circ_{2\,1/2}$ |
| 1511.185 | 8 | 66173.23 | $s^2\ ^4F_{3\,1/2} - 5p'\ ^2F^\circ_{2\,1/2}$ |
| 1511.314 | 3 | 66167.59 | $4p'\ ^2F^\circ_{2\,1/2} - 6s''\ ^2P_{1\,1/2}$ |
| 1511.467 | 10 | 66160.89 | |
| 1512.237 | 1 | 66127.20 | $s^2\ ^4P_{1\,1/2} - s\ ^4D^\circ_{0\,1/2}$ |
| 1512.742 | 11 | 66105.12 | $s^2\ ^2G_{3\,1/2} - 8p\ ^2G^\circ_{3\,1/2}$ |
| 1513.016 | 11 | 66093.15 | $s^2\ ^4P_{2\,1/2} - s\ ^4D^\circ_{2\,1/2}$ |
| | | | $s^2\ ^4P_{1\,1/2} - 6f\ ^4P^\circ_{1\,1/2}$ |
| 1513.550 | 1 | 66069.83 | $4p\ ^4F^\circ_{2\,1/2} - 5d\ ^4G_{2\,1/2}$ |
| 1513.783 | 15 | 66059.67 | $4p''\ ^4D^\circ_{1\,1/2} - 5d''\ ^4F_{2\,1/2}$ |
| 1514.222 | 50 | 66040.51 | $4p'\ ^2F^\circ_{2\,1/2} - 5d'\ ^2F_{2\,1/2}$ |
| 1514.336 | 10 | 66035.54 | |
| 1514.372 | 80 | 66033.97 | $s^2\ ^2G_{4\,1/2} - 6p'\ ^2F^\circ_{3\,1/2}$ |
| 1514.411 | 17 | 66032.27 | |
| 1514.552 | 5 | 66026.12 | $4p''\ ^4D^\circ_{1\,1/2} - 5d''\ ^4F_{1\,1/2}$ |
| 1514.633 | 6 | 66022.59 | |
| 1514.644 | 2 | 66022.11 | |
| 1514.856 | 8 | 66012.87 | $4p'\ ^2P^\circ_{1\,1/2} - 7d\ ^4D_{2\,1/2}$ |
| 1515.157 | 15 | 65999.76 | $s^2\ ^4P_{1\,1/2} - s\ ^4D^\circ_{1\,1/2}$ |
| 1515.269 | 25 | 65994.88 | $4p\ ^2G^\circ_{4\,1/2} - 5d\ ^2G_{4\,1/2}$ |
| 1515.329 | 8 | 65992.27 | $4s'\ ^2D_{2\,1/2} - z\ ^6D^\circ_{3\,1/2}$ |
| 1515.518 | 5 | 65984.04 | $4p''\ ^4D^\circ_{0\,1/2} - 5d''\ ^4F_{1\,1/2}$ |
| 1515.692 | 1 | 65976.46 | $4p''\ ^4D^\circ_{0\,1/2} - 5d''\ ^4P_{0\,1/2}$ |
| 1515.791 | 30 | 65972.16 | $4p\ ^4F^\circ_{2\,1/2} - 5d\ ^4H_{3\,1/2}$ |
| 1515.625 | 40 | 65970.68 | $s^2\ ^4P_{2\,1/2} - s\ ^4D^\circ_{3\,1/2}$ |
| 1516.048 | 17 | 65960.97 | $4p'\ ^2P^\circ_{0\,1/2} - 6s''\ ^2P_{0\,1/2}$? |
| 1516.215 | 50 | 65953.71 | $4p''\ ^4D^\circ_{2\,1/2} - 5d''\ ^4F_{3\,1/2}$ |
| 1516.503 | 3 | 65941.18 | $4p\ ^2G^\circ_{4\,1/2} - 5d\ ^2F_{3\,1/2}$ |
| 1517.449 | 25 | 65900.07 | $4p\ ^4F^\circ_{3\,1/2} - 5d\ ^4G_{3\,1/2}$ |
| 1517.480 | 40 | 65898.73 | $4p\ ^2G^\circ_{3\,1/2} - 5d\ ^2G_{3\,1/2}$ |
| | | | $4p'\ ^2D^\circ_{1\,1/2} - 5d'\ ^2D_{2\,1/2}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 1517.894 | 100 | 65880.75 | $4p\ ^2G^\circ_{4\frac{1}{2}} - 5d\ ^2H_{5\frac{1}{2}}$ |
| 1517.984 | 15 | 65876.85 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 5d\ ^2G_{4\frac{1}{2}}$ |
| 1519.371 | 40 | 65816.71 | $s^2\ ^4P_{1\frac{1}{2}} - s\ ^4D^\circ_{2\frac{1}{2}}$ |
| 1519.513 | 15 | 65810.56 | |
| 1519.745 | 4 | 65800.51 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 5d'\ ^2P_{0\frac{1}{2}}$ |
| 1519.935 | 100 | 65792.29 | $4p'\ ^2F^\circ_{3\frac{1}{2}} - 5d'\ ^2G_{4\frac{1}{2}}$? |
| 1520.008 | 2 | 65789.13 | |
| 1520.077 | 4 | 65786.14 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 4d'\ ^2P_{1\frac{1}{2}}$ |
| 1520.168 | 14 | 65782.20 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 5d\ ^4G_{4\frac{1}{2}}$ |
| 1520.294 | 10 | 65776.75 | |
| 1520.392 | 30 | 65772.51 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 5d\ ^4H_{4\frac{1}{2}}$ |
| 1520.467 | 40 | 65769.27 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 5d\ ^2H_{4\frac{1}{2}}$ |
| 1520.932 | 10 | 65749.16 | $4p'\ ^2F^\circ_{2\frac{1}{2}} - 6s''\ ^4P_{2\frac{1}{2}}$ |
| 1520.944 | 20 | 65748.64 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 5d'\ ^2D_{1\frac{1}{2}}$ |
| 1521.119 | 100 | 65741.08 | $4p''\ ^4D^\circ_{3\frac{1}{2}} - 5d''\ ^4F_{4\frac{1}{2}}$ |
| 1521.596 | 15 | 65720.47 | $4p\ ^4F^\circ_{1\frac{1}{2}} - 5d\ ^4G_{2\frac{1}{2}}$ |
| 1521.673 | 18 | 65717.14 | $s^2\ ^2G_{4\frac{1}{2}} - v\ ^2G^\circ_{4\frac{1}{2}}$ |
| 1521.889 | 12 | 65707.81 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 6s''\ ^2P_{1\frac{1}{2}}$ |
| 1521.992 | 10 | 65703.37 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 6s''\ ^4P_{0\frac{1}{2}}$ |
| 1522.506 | 2 | 65681.19 | |
| 1522.517 | 0 | 65680.71 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 6s\ ^2F_{2\frac{1}{2}}$ |
| 1522.569 | 30 | 65678.47 | $4p'\ ^2F^\circ_{3\frac{1}{2}} - 8s\ ^4F_{3\frac{1}{2}}$ |
| 1522.691 | 10 | 65673.21 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 5d'\ ^2P_{0\frac{1}{2}}$ |
| 1522.846 | 12 | 65666.52 | $s^2\ ^4F_{3\frac{1}{2}} - 5p'\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1522.990 | 11 | 65660.31 | $4p\ ^4F^\circ_{1\frac{1}{2}} - 5d\ ^4F_{1\frac{1}{2}}$ |
| 1523.102 | 3 | 65655.48 | |
| 1523.160 | 6 | 65652.98 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 5d''\ ^4D_{2\frac{1}{2}}$ |
| 1523.278 | 30 | 65647.90 | $s^2\ ^4P_{2\frac{1}{2}} - v\ ^4F^\circ_{3\frac{1}{2}}$ |
| 1523.897 | 15h | 65621.23 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 5d'\ ^2D_{1\frac{1}{2}}$ |
| | | | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 5d''\ ^4D_{1\frac{1}{2}}$ |
| 1524.302 | 50 | 65603.80 | $4p''\ ^2F^\circ_{3\frac{1}{2}} - 5d'\ ^2F_{3\frac{1}{2}}$ |
| 1524.758 | 4 | 65584.18 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 5d''\ ^4D_{0\frac{1}{2}}$ |
| 1524.834 | 22 | 65580.91 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 5d'\ ^2D_{1\frac{1}{2}}$ |
| 1524.996 | 14 | 65573.94 | $s^2\ ^4P_{0\frac{1}{2}} - s\ ^4D^\circ_{0\frac{1}{2}}$ |
| 1525.422 | 8 | 65555.63 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 6s\ ^2F_{3\frac{1}{2}}$ |
| 1526.480 | 4 | 65510.19 | $4p''\ ^4D^\circ_{3\frac{1}{2}} - 5d''\ ^4D_{2\frac{1}{2}}$ |
| 1526.999 | 20 | 65487.93 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 5d\ ^4G_{4\frac{1}{2}}$ |
| 1527.497 | 15 | 65466.58 | $s^2\ ^4F_{4\frac{1}{2}} - v\ ^4D^\circ_{3\frac{1}{2}}$ |
| 1527.661 | 1 | 65459.55 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 6s''\ ^4P_{1\frac{1}{2}}$ |
| 1527.968 | 18 | 65446.40 | $s^2\ ^4P_{0\frac{1}{2}} - s\ ^4D^\circ_{1\frac{1}{2}}$ |
| 1528.158 | 3 | 65438.26 | |
| 1528.508 | 22 | 65423.28 | $4p''\ ^4D^\circ_{3\frac{1}{2}} - 5d''\ ^4D_{3\frac{1}{2}}$ |
| 1528.703 | 1 | 65414.93 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 8s\ ^2F_{2\frac{1}{2}}$ |
| 1529.148 | 4 | 65395.89 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 7d\ ^2D_{2\frac{1}{2}}$ |
| 1529.812 | 0 | 65367.51 | $s^2\ ^4F_{3\frac{1}{2}} - w\ ^4F^\circ_{4\frac{1}{2}}$ |
| 1530.080 | 18 | 65356.06 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 5d\ ^4F_{4\frac{1}{2}}$ |
| 1530.428 | 10 | 65341.20 | $s^2\ ^4F_{2\frac{1}{2}} - 5p'\ ^2F^\circ_{2\frac{1}{2}}$ |
| 1530.636 | 75 | 65332.32 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 5d\ ^4G_{3\frac{1}{2}}$ |
| | | | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 6s''\ ^4P_{1\frac{1}{2}}$ |
| 1530.663 | 30 | 65331.17 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 8d\ ^4P_{2\frac{1}{2}}$ |
| 1530.995 | 16 | 65317.00 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 5d'\ ^2D_{2\frac{1}{2}}$ |
| 1531.288 | 3 | 65304.50 | |
| 1531.336 | 1 | 65302.45 | |
| 1531.408 | 14 | 65299.38 | |
| 1531.640 | 18 | 65289.49 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 6s''\ ^4P_{2\frac{1}{2}}$ |
| 1531.720 | 1 | 65286.08 | $s^2\ ^2G_{4\frac{1}{2}} - 6f\ ^2H^\circ_{5\frac{1}{2}}$ |
| 1531.952 | 16 | 65276.20 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 6s''\ ^2P_{0\frac{1}{2}}$ |
| 1531.972 | 20 | 65275.34 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 6s\ ^4F_{4\frac{1}{2}}$ |
| 1532.741 | 14 | 65242.59 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 5d\ ^4G_{3\frac{1}{2}}$ |
| 1533.669 | 17 | 65203.12 | |
| 1533.885 | 12 | 65193.94 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 5d'\ ^2G_{3\frac{1}{2}}$ |
| 1533.991 | 20 | 65189.43 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 5d\ ^2G_{3\frac{1}{2}}$ |
| 1534.424 | 5 | 65171.03 | |
| 1534.484 | 12 | 65168.49 | |
| 1534.546 | 11 | 65165.85 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 5d\ ^2F_{3\frac{1}{2}}$ |
| 1534.628 | 1 | 65162.37 | |
| 1534.861 | 10 | 65152.48 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 5d\ ^4F_{2\frac{1}{2}}$ |
| 1535.083 | 2 | 65143.06 | |
| 1535.477 | 12 | 65126.34 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 6s''\ ^2P_{1\frac{1}{2}}$ |
| 1535.961 | 15 | 65105.82 | $s^2\ ^2G_{4\frac{1}{2}} - 4f''\ ^2G^\circ_{3\frac{1}{2}}$ |
| 1536.051 | 30 | 65102.00 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 5d'\ ^2P_{1\frac{1}{2}}$ |
| 1536.118 | 15 | 65099.17 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 5d\ ^4D_{3\frac{1}{2}}$ |
| 1536.367 | 1 | 65088.61 | |
| 1536.398 | 20 | 65087.30 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 5d'\ ^2D_{2\frac{1}{2}}$ |
| 1536.717 | 15 | 65073.79 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 8s\ ^4F_{3\frac{1}{2}}$ |
| 1536.746 | 25 | 65072.56 | $3d\ ^2D_{1\frac{1}{2}} - 4p''\ ^4P^\circ_{1\frac{1}{2}}$ |
| 1536.779 | 10 | 65071.16 | |
| 1536.944 | 12 | 65064.18 | $3d\ ^2D_{1\frac{1}{2}} - 4p''\ ^4P^\circ_{2\frac{1}{2}}$ |
| 1537.038 | 12 | 65060.20 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 5d\ ^2H_{4\frac{1}{2}}$ |
| 1537.216 | 20 | 65052.67 | $s^2\ ^4P_{1\frac{1}{2}} - v\ ^4F^\circ_{2\frac{1}{2}}$ |
| 1537.322 | 2 | 65048.18 | |
| 1537.477 | 15 | 65041.62 | $s^2\ ^2G_{4\frac{1}{2}} - 4f''\ ^2F^\circ_{3\frac{1}{2}}$ |
| 1537.776 | 1 | 65028.98 | |
| 1537.859 | 25 | 65025.47 | |
| 1538.022 | 6 | 65018.58 | |
| 1538.388 | 30 | 65003.11 | |
| 1538.483 | 30 | 64999.09 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 5d'\ ^2F_{3\frac{1}{2}}$ |
| 1538.567 | 4 | 64995.54 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 5d''\ ^4F_{2\frac{1}{2}}$ |
| 1538.722 | 0 | 64989.00 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 5d'\ ^2P_{0\frac{1}{2}}$ |
| 1538.831 | 3 | 64984.39 | $4p\ ^4G^\circ_{2\frac{1}{2}} - 5d\ ^4F_{3\frac{1}{2}}$ |
| 1538.956 | 1 | 64979.12 | |
| 1539.649 | 15 | 64949.87 | |
| 1539.731 | 1 | 64946.41 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 5d\ ^4G_{3\frac{1}{2}}$ |
| 1539.949 | 2 | 64937.21 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 5d'\ ^2D_{1\frac{1}{2}}$ |
| 1540.015 | 1 | 64934.43 | $s^2\ ^4F_{2\frac{1}{2}} - w\ ^4F^\circ_{3\frac{1}{2}}$ |
| 1540.281 | 25 | 64923.22 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 5d\ ^2G_{4\frac{1}{2}}$ |
| 1540.656 | 1 | 64907.42 | |
| 1540.760 | 35 | 64903.03 | $s^2\ ^2G_{4\frac{1}{2}} - 8p\ ^4G^\circ_{4\frac{1}{2}}$ |
| 1540.908 | 4 | 64896.80 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 6s''\ ^2P_{1\frac{1}{2}}$ |
| 1541.324 | 14 | 64879.29 | |
| 1541.356 | 11 | 64877.94 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 6s''\ ^4P_{1\frac{1}{2}}$ |
| 1541.560 | 4 | 64869.35 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 5d\ ^2F_{3\frac{1}{2}}$ |
| 1541.801 | 2 | 64859.21 | $4p'''\ ^2H^\circ_{4\frac{1}{2}} - 6s'''\ ^2G_{3\frac{1}{2}}$ |
| 1542.024 | 1 | 64849.83 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 5d\ ^2G_{3\frac{1}{2}}$ |
| 1542.208 | 18 | 64842.10 | |
| 1542.238 | 2 | 64840.83 | |
| 1542.263 | 3 | 64839.78 | |
| 1542.388 | 1 | 64834.53 | $s^2\ ^4F_{2\frac{1}{2}} - 5p'\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1542.401 | 3 | 64833.98 | |
| 1542.773 | 15 | 64818.35 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 5d''\ ^4F_{3\frac{1}{2}}$ |
| 1543.132 | 1 | 64803.27 | $4p\ ^4F^\circ_{1\frac{1}{2}} - 5d\ ^4F_{2\frac{1}{2}}$ |
| 1543.806 | 3 | 64774.98 | |
| 1544.273 | 3 | 64755.39 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 5d\ ^2F_{2\frac{1}{2}}$ |
| 1544.968 | 5 | 64726.26 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 5d\ ^4D_{2\frac{1}{2}}$ |
| 1544.980 | 10 | 64725.76 | |
| 1545.408 | 30 | 64707.83 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 6s''\ ^4P_{2\frac{1}{2}}$ |
| 1545.453 | 12 | 64705.95 | |
| 1545.717 | 16 | 64694.90 | |
| 1545.881 | 5 | 64688.03 | $s^2\ ^4F_{3\frac{1}{2}} - v\ ^4D^\circ_{2\frac{1}{2}}$ |



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TABLE I. *Lines of* Ni II – Continued

| λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 1546.053 | 1 | 64680.84 | |
| 1546.070 | 4 | 64680.12 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 6s\ ^4F_{2\frac{1}{2}}$ |
| 1547.337 | 15 | 64627.16 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 5d\ ^4G_{4\frac{1}{2}}$ |
| | | | $4p\ ^2D^\circ_{2\frac{1}{2}} - 5d\ ^4H_{3\frac{1}{2}}$ |
| 1547.407 | 13 | 64624.24 | $s^2\ ^4F_{2\frac{1}{2}} - v\ ^4D^\circ_{1\frac{1}{2}}$ |
| 1547.513 | 5 | 64619.81 | |
| 1547.547 | 3 | 64618.39 | $s^2\ ^2G_{2\frac{1}{2}} - v\ ^2G^\circ_{4\frac{1}{2}}$ |
| | | | $s^2\ ^4F_{3\frac{1}{2}} - w\ ^4G^\circ_{2\frac{1}{2}}$ |
| 1548.344 | 16 | 64585.13 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 5d\ ^4F_{3\frac{1}{2}}$ |
| 1548.416 | 7 | 64582.13 | |
| 1549.588 | 1 | 64533.28 | $4p\ ^2G^\circ_{4\frac{1}{2}} - 5d\ ^4H_{5\frac{1}{2}}$ |
| 1549.818 | 0 | 64523.71 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 5d''\ ^4P_{1\frac{1}{2}}$ |
| 1549.964 | 4 | 64517.63 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 5d''\ ^4D_{2\frac{1}{2}}$ |
| 1550.479 | 3 | 64496.20 | $s^2\ ^2G_{3\frac{1}{2}} - 4f''\ ^4D^\circ_{3\frac{1}{2}}$ |
| 1550.495 | 2 | 64495.53 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 5d\ ^4F_{4\frac{1}{2}}$ |
| 1550.912 | 10 | 64478.19 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 6s''\ ^4P_{2\frac{1}{2}}$ |
| 1552.276 | 5 | 64421.53 | $s^2\ ^2G_{3\frac{1}{2}} - 4f''\ ^4G^\circ_{3\frac{1}{2}}$ |
| 1553.012 | 00 | 64391.00 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 5d''\ ^4F_{2\frac{1}{2}}$ |
| 1553.346 | 4 | 64377.16 | |
| 1554.108 | 5 | 64345.59 | |
| 1554.124 | 50 | 64344.93 | $s^2\ ^4P_{2\frac{1}{2}} - v\ ^4P^\circ_{1\frac{1}{2}}$ |
| 1554.293 | 8 | 64337.93 | |
| 1554.332 | 8 | 64336.32 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 6s\ ^4F_{3\frac{1}{2}}$ |
| 1554.509 | 6 | 64328.99 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 6s'\ ^2D_{2\frac{1}{2}}$? |
| 1555.062 | 2 | 64306.12 | $s^2\ ^4F_{3\frac{1}{2}} - v\ ^4D^\circ_{3\frac{1}{2}}$ |
| 1555.398 | 16 | 64292.23 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 5d''\ ^2P_{1\frac{1}{2}}$? |
| 1555.496 | 30 | 64288.18 | $s^2\ ^2G_{3\frac{1}{2}} - v\ ^2G^\circ_{3\frac{1}{2}}$ |
| 1555.585 | 8 | 64284.50 | $4p'''\ ^2H^\circ_{5\frac{1}{2}} - 6s'''\ ^2G_{4\frac{1}{2}}$ |
| 1555.957 | 13 | 64269.13 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 4d''\ ^4F_{3\frac{1}{2}}$ |
| 1556.350 | 7 | 64252.90 | |
| 1556.766 | 10 | 64235.73 | |
| 1556.997 | 4 | 64226.20 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 5d''\ ^2P_{0\frac{1}{2}}$ |
| 1557.194 | 1 | 64218.07 | $s^2\ ^4P_{0\frac{1}{2}} - 4f'\ ^2D^\circ_{1\frac{1}{2}}$ |
| 1557.290 | 12 | 64214.12 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 5d\ ^2G_{4\frac{1}{2}}$ |
| 1557.380 | 1 | 64210.40 | |
| 1558.087 | 10 | 64181.27 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 4d''\ ^4F_{4\frac{1}{2}}$ |
| 1558.443 | 12 | 64166.61 | |
| 1558.501 | 2 | 64164.22 | $s^2\ ^4F_{4\frac{1}{2}} - x\ ^4G^\circ_{3\frac{1}{2}}$ |
| 1558.544 | 5 | 64162.45 | $s^2\ ^4F_{1\frac{1}{2}} - 5p'\ ^2D^\circ_{1\frac{1}{2}}$ |
| 1558.597 | 15 | 64160.27 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 5d\ ^2F_{3\frac{1}{2}}$ |
| 1558.655 | 40 | 64157.88 | |
| 1559.159 | 18 | 64137.14 | |
| 1559.822 | 1 | 64109.88 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 5d\ ^4H_{4\frac{1}{2}}$ |
| 1560.341 | 6 | 64088.55 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 6s'''\ ^2G_{4\frac{1}{2}}$ |
| 1560.459 | 25 | 64083.71 | |
| 1560.517 | 10 | 64081.33 | $4p\ ^4G^\circ_{2\frac{1}{2}} - 6s\ ^4F_{1\frac{1}{2}}$ |
| 1560.562 | 4 | 64079.48 | |
| 1560.796 | 5 | 64069.87 | $s^2\ ^4F_{3\frac{1}{2}} - w\ ^4G^\circ_{3\frac{1}{2}}$ |
| 1560.831 | 15 | 64068.44 | $s^2\ ^4P_{1\frac{1}{2}} - v\ ^4P^\circ_{1\frac{1}{2}}$ |
| 1560.935 | 4 | 64064.17 | $s^2\ ^4F_{3\frac{1}{2}} - w\ ^4G^\circ_{3\frac{1}{2}}$ |
| 1561.015 | 4 | 64060.88 | $s^2\ ^4F_{1\frac{1}{2}} - v\ ^4D^\circ_{1\frac{1}{2}}$ |
| 1561.229 | 15 | 64052.10 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 6s\ ^4F_{2\frac{1}{2}}$ |
| 1561.733 | 2 | 64031.43 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 6s\ ^2F_{3\frac{1}{2}}$ |
| 1561.968 | 11 | 64021.80 | $s^2\ ^2G_{4\frac{1}{2}} - w\ ^2G^\circ_{3\frac{1}{2}}$ |
| 1562.329 | 18 | 64007.00 | $s^2\ ^2G_{3\frac{1}{2}} - 4f''\ ^2G^\circ_{3\frac{1}{2}}$ |
| 1563.111 | 7 | 63974.98 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 5d''\ ^4P_{2\frac{1}{2}}$ |
| 1563.376 | 50 | 63964.14 | $s^2\ ^4P_{1\frac{1}{2}} - v\ ^4P^\circ_{0\frac{1}{2}}$ |
| 1563.604 | 120 | 63954.81 | $s^2\ ^4F_{4\frac{1}{2}} - w\ ^4D^\circ_{3\frac{1}{2}}$ |
| | | | $s^2\ ^4P_{2\frac{1}{2}} - v\ ^4P^\circ_{2\frac{1}{2}}$ |
| 1563.837 | 1 | 63945.28 | |
| 1564.273 | 15 | 63927.46 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 5d\ ^4F_{3\frac{1}{2}}$ |
| 1564.389 | 8 | 63922.72 | |
| 1565.001 | 1 | 63897.72 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 6s\ ^2F_{2\frac{1}{2}}$ |
| | | | $4p\ ^2D^\circ_{2\frac{1}{2}} - 5d\ ^4G_{3\frac{1}{2}}$ |
| 1565.399 | 20 | 63881.48 | $4s^2\ ^4F_{3\frac{1}{2}} - w\ ^4G^\circ_{4\frac{1}{2}}$ |
| 1565.970 | 3 | 63858.18 | |
| 1566.019 | 7 | 63856.19 | $s^2\ ^4F_{2\frac{1}{2}} - v\ ^4D^\circ_{2\frac{1}{2}}$ |
| 1566.890 | 1 | 63820.69 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 5d\ ^2F_{3\frac{1}{2}}$ |
| 1567.069 | 15 | 63813.40 | $s^2\ ^4F_{4\frac{1}{2}} - w\ ^4G^\circ_{5\frac{1}{2}}$ |
| 1567.220 | 10 | 63807.25 | |
| 1567.298 | 3 | 63804.08 | $s^2\ ^2G_{3\frac{1}{2}} - 8p\ ^4G^\circ_{4\frac{1}{2}}$ |
| 1567.323 | 10 | 63803.06 | |
| 1567.336 | 12 | 63802.53 | |
| 1567.370 | 3 | 63801.14 | $s^2\ ^2G_{3\frac{1}{2}} - v\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1567.872 | 1 | 63780.72 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 5d''\ ^4F_{2\frac{1}{2}}$ |
| 1567.966 | 4 | 63776.89 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 5d\ ^2G_{3\frac{1}{2}}$ |
| 1568.698 | 1 | 63747.13 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 5d''\ ^4F_{1\frac{1}{2}}$ |
| 1569.172 | 16 | 63727.88 | |
| 1569.415 | 1 | 63718.01 | |
| 1569.624 | 13 | 63709.53 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 6s\ ^4F_{3\frac{1}{2}}$ |
| 1569.972 | 2 | 63695.40 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 5d\ ^2P_{1\frac{1}{2}}$ |
| 1570.302 | 10 | 63682.02 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 5d\ ^2F_{2\frac{1}{2}}$ |
| 1570.392 | 60 | 63678.37 | $s^2\ ^4P_{1\frac{1}{2}} - v\ ^4P^\circ_{2\frac{1}{2}}$ |
| 1570.512 | 3 | 63673.50 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 5d\ ^4G_{4\frac{1}{2}}$ |
| 1570.701 | 1 | 63665.84 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 7s\ ^2F_{2\frac{1}{2}}$ |
| 1570.879 | 1 | 63658.63 | |
| 1571.145 | 12 | 63647.85 | |
| 1571.162 | 12 | 63647.16 | |
| 1571.257 | 10 | 63643.31 | |
| 1571.532 | 2 | 63632.18 | |
| 1571.550 | 2 | 63631.45 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 5d\ ^4F_{3\frac{1}{2}}$ |
| 1572.018 | 4 | 63612.50 | |
| 1572.062 | 4 | 63610.72 | |
| 1572.540 | 25 | 63591.39 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 5d\ ^4F_{1\frac{1}{2}}$ |
| 1572.646 | 4 | 63587.10 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 4d'''\ ^2F_{2\frac{1}{2}}$ |
| 1572.993 | 1 | 63573.07 | |
| 1573.071 | 10 | 63569.92 | |
| 1574.202 | 18 | 63524.25 | |
| 1574.423 | 100 | 63515.33 | $s^2\ ^4P_{0\frac{1}{2}} - v\ ^4P^\circ_{1\frac{1}{2}}$ |
| 1574.942 | 20 | 63494.40 | |
| 1574.976 | 5 | 63493.03 | $4p''\ ^4D^\circ_{0\frac{1}{2}} - 6s''\ ^2P_{0\frac{1}{2}}$ |
| 1575.003 | 16 | 63491.94 | $s^2\ ^2G_{4\frac{1}{2}} - s\ ^4D^\circ_{3\frac{1}{2}}$ |
| 1575.090 | 15 | 63488.44 | |
| 1575.559 | 1 | 63469.54 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 5d\ ^2F_{2\frac{1}{2}}$ |
| 1575.597 | 9 | 63468.01 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 6s\ ^4F_{4\frac{1}{2}}$ |
| 1576.747 | 1 | 63421.72 | |
| 1577.015 | 30 | 63410.94 | $s^2\ ^4P_{0\frac{1}{2}} - v\ ^4P^\circ_{0\frac{1}{2}}$ |
| 1577.115 | 16 | 63406.92 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 5d\ ^2P_{0\frac{1}{2}}$ |
| 1577.210 | 7 | 63403.10 | |
| 1577.933 | 14 | 63374.05 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 4d'''\ ^2F_{2\frac{1}{2}}$ |
| 1578.865 | 20 | 63336.64 | $4p\ ^4G^\circ_{5\frac{1}{2}} - 6s\ ^4F_{4\frac{1}{2}}$ |
| 1578.990 | 60 | 63331.62 | |
| 1579.073 | 18 | 63328.29 | |
| 1579.563 | 18 | 63308.65 | $4p''\ ^2P^\circ_{0\frac{1}{2}} - 5d''\ ^2P_{0\frac{1}{2}}$ |
| 1579.791 | 17 | 63299.51 | |
| 1579.877 | 2 | 63296.07 | $4p\ ^4G^\circ_{2\frac{1}{2}} - 6s\ ^4F_{2\frac{1}{2}}$ |
| 1579.959 | 3 | 63292.78 | $s^2\ ^4F_{1\frac{1}{2}} - v\ ^4D^\circ_{2\frac{1}{2}}$ |
| 1580.588 | 8 | 63267.59 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 5d'\ ^2D_{1\frac{1}{2}}$ |
| 1580.674 | 1 | 63264.15 | |
| 1580.698 | 2 | 63263.19 | |

TABLE I. *Lines of* Ni II – Continued

| λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 1581.085 | 6 | 63247.71 | $4p'\ ^2F^\circ_{2½} - 6s'\ ^2D_{1½}$ |
| 1581.334 | 25 | 63237.75 | $s^2\ ^4F_{2½} - w\ ^4G^\circ_{3½}$ |
| 1581.704 | 10 | 63222.95 | $s^2\ ^4F_{1½} - w\ ^4G^\circ_{2½}$ |
| 1581.826 | 6 | 63218.08 | $4p\ ^4D^\circ_{2½} - 4d''\ ^4F_{2½}$ |
| 1582.135 | 2 | 63205.73 | $4p\ ^2F^\circ_{2½} - 5d\ ^4D_{1½}$ |
| 1582.373 | 00 | 63196.22 | $4p''\ ^4D^\circ_{1½} - 5d'\ ^2D_{1½}$ |
| | | | $4p''\ ^2P^\circ_{0½} - 5d''\ ^4P_{1½}$ |
| 1582.571 | 2 | 63188.32 | |
| 1582.689 | 10 | 63183.61 | |
| 1583.051 | 17 | 63169.16 | $s^2\ ^2G_{4½} - v\ ^4F^\circ_{3½}$ |
| 1583.398 | 1 | 63155.32 | $4p''\ ^4D^\circ_{1½} - 6s''\ ^2P_{1½}$ |
| 1583.436 | 10 | 63153.80 | |
| 1583.509 | 15 | 63150.89 | $4p''\ ^4D^\circ_{1½} - 6s''\ ^4P_{0½}$ |
| 1584.530 | 10 | 63110.20 | |
| 1584.563 | 16 | 63108.88 | $4p''\ ^4D^\circ_{0½} - 6s''\ ^4P_{0½}$ |
| 1584.761 | 1 | 63101.00 | |
| 1585.117 | 200 | 63086.83 | $s^2\ ^2G_{4½} - w\ ^2G^\circ_{4½}$ |
| 1585.702 | 4 | 63063.55 | $4p\ ^2F^\circ_{3½} - 5d\ ^4D_{2½}$ |
| 1586.677 | 4 | 63024.80 | $4p\ ^4F^\circ_{2½} - 6s\ ^4F_{1½}$ |
| 1587.138 | 3 | 63006.49 | $s^2\ ^4F_{4½} - x\ ^4F^\circ_{3½}$ |
| 1587.207 | 8 | 63003.75 | $s^2\ ^4F_{3½} - x\ ^4G^\circ_{3½}$ |
| 1587.443 | 18 | 62994.39 | $4p\ ^2G^\circ_{4½} - 6s\ ^2F_{3½}$ |
| 1587.845 | 35 | 62978.44 | $4p''\ ^4D^\circ_{2½} - 6s''\ ^4P_{1½}$ |
| 1588.200 | 10 | 62964.36 | $4p\ ^2F^\circ_{3½} - 5d\ ^4G_{4½}$ |
| 1588.369 | 15 | 62957.66 | |
| 1588.464 | 10 | 62953.90 | |
| 1588.715 | 9 | 62943.95 | $4p\ ^2G^\circ_{3½} - 6s\ ^2F_{2½}$ |
| 1588.798 | 20 | 62940.66 | |
| 1589.061 | 40 | 62930.25 | |
| 1589.116 | 80 | 62928.07 | |
| 1589.246 | 200 | 62922.92 | $s^2\ ^2G_{3½} - w\ ^2G^\circ_{3½}$ |
| 1589.474 | 5 | 62913.89 | $s^2\ ^4F_{3½} - x\ ^4F^\circ_{2½}$ |
| 1589.547 | 1 | 62911.01 | $4p''\ ^4S^\circ_{1½} - 5d''\ ^2P_{0½}$ |
| 1589.563 | 3 | 62910.37 | |
| 1589.644 | 20 | 62907.17 | $4p''\ ^4D^\circ_{1½} - 6s''\ ^4P_{1½}$ |
| 1589.772 | 80 | 62902.10 | $s^2\ ^4F_{3½} - w\ ^4D^\circ_{2½}$ |
| 1589.903 | 8 | 62896.92 | $4p\ ^4F^\circ_{3½} - 6s\ ^4F_{2½}$ |
| 1589.948 | 7 | 62895.14 | |
| 1590.422 | 0 | 62876.39 | $4p\ ^4F^\circ_{3½} - 6s\ ^2F_{3½}$ |
| 1590.529 | 10 | 62872.16 | |
| 1590.703 | 1 | 62865.29 | $4p''\ ^4D^\circ_{0½} - 6s''\ ^4P_{1½}$ |
| 1591.041 | 50 | 62851.93 | $4s\ ^2F_{3½} - 4p'''\ ^2F^\circ_{2½}$ |
| 1591.099 | 16 | 62849.64 | |
| 1591.350 | 10 | 62839.73 | |
| 1591.415 | 80 | 62837.16 | $s^2\ ^2G_{3½} - 6f\ ^4D^\circ_{2½}$ |
| 1591.732 | 2 | 62824.65 | $4p\ ^2F^\circ_{2½} - 5d\ ^4G_{3½}$ |
| 1592.080 | 200 | 62810.91 | $s^2\ ^2G_{4½} - w\ ^2F^\circ_{3½}$ |
| 1592.144 | 15 | 62808.39 | $4p''\ ^4D^\circ_{2½} - 6s''\ ^4P_{2½}$ |
| 1592.248 | 25 | 62804.29 | |
| 1592.479 | 50 | 62795.18 | |
| 1592.502 | 15 | 62794.27 | $s^2\ ^4F_{3½} - w\ ^4D^\circ_{3½}$ |
| 1592.662 | 1 | 62787.96 | $4p'\ ^2D^\circ_{1½} - 6s'\ ^2D_{1½}$ |
| | | | $4p'\ ^2D^\circ_{1½} - 6d\ ^4D_{1½}$ |
| 1593.132 | 1 | 62769.44 | $4p'\ ^2F^\circ_{3½} - 6s'\ ^2D_{2½}$ |
| 1593.200 | 15 | 62766.76 | |
| 1593.522 | 15 | 62754.08 | |
| 1593.611 | 150 | 62750.57 | $s^2\ ^2G_{3½} - w\ ^2F^\circ_{2½}$ |
| 1593.698 | 40 | 62747.15 | $s^2\ ^4F_{2½} - t\ ^2D^\circ_{1½}$ |
| 1594.019 | 1 | 62734.51 | $4p\ ^2F^\circ_{2½} - 5d\ ^4F_{2½}$ |
| 1594.287 | 6 | 62723.96 | $4p\ ^2D^\circ_{2½} - 5d\ ^4D_{2½}$ |
| 1594.346 | 35 | 62721.64 | |
| 1594.575 | 1 | 62712.63 | |
| 1594.703 | 12 | 62707.60 | $s^2\ ^4F_{4½} - x\ ^4G^\circ_{4½}$ |
| 1595.332 | 1 | 62682.88 | |
| 1595.519 | 8 | 62675.53 | $4p\ ^4F^\circ_{1½} - 6s\ ^4F_{1½}$ |
| 1595.608 | 70 | 62672.03 | $s^2\ ^2G_{4½} - 4f'\ ^2H^\circ_{4½}$ |
| 1595.768 | 70 | 62665.75 | $4p''\ ^4D^\circ_{3½} - 6s''\ ^4P_{2½}$ |
| 1595.919 | 15 | 62659.82 | $4p''\ ^4S^\circ_{1½} - 5d''\ ^4P_{2½}$ |
| 1596.074 | 60 | 62653.74 | |
| 1596.874 | 1 | 62622.35 | $4p\ ^2F^\circ_{2½} - 5d\ ^2P_{1½}$ |
| 1597.031 | 1 | 62616.19 | $4p''\ ^2S^\circ_{0½} - 5d''\ ^4P_{1½}$ |
| 1597.101 | 25 | 62613.45 | |
| 1597.484 | 9 | 62598.44 | $4p''\ ^4S^\circ_{1½} - 5d''\ ^4P_{1½}$ |
| 1597.886 | 7 | 62582.69 | $4p\ ^2D^\circ_{2½} - 5d\ ^4F_{3½}$ |
| 1598.282 | 40 | 62567.18 | |
| 1598.315 | 4 | 62565.89 | |
| 1598.371 | 30 | 62563.70 | |
| 1598.860 | 18 | 62544.56 | |
| 1599.251 | 40 | 62529.27 | |
| 1599.282 | 12 | 62528.06 | $s^2\ ^4F_{2½} - x\ ^4G^\circ_{2½}$ |
| 1599.439 | 1 | 62521.92 | $4p\ ^2D^\circ_{1½} - 5d\ ^4F_{2½}$ |
| 1599.549 | 10 | 62517.62 | $4p\ ^4F^\circ_{4½} - 6s\ ^4F_{3½}$ |
| 1599.603 | 25 | 62515.51 | $s^2\ ^2G_{3½} - s\ ^4D^\circ_{2½}$ |
| 1600.268 | 10 | 62489.53 | $4p\ ^2D^\circ_{2½} - 5d\ ^4P_{1½}$ |
| 1600.565 | 18 | 62477.94 | |
| 1600.753 | 3 | 62470.60 | |
| 1601.045 | 16 | 62459.21 | $s^2\ ^2G_{4½} - 4f'\ ^2G^\circ_{4½}$ |
| 1601.240 | 10 | 62451.60 | $s^2\ ^4P_{2½} - t\ ^4D^\circ_{1½}$ |
| 1601.288 | 8 | 62449.73 | $4p''\ ^2S^\circ_{0½} - 4d''\ ^2F_{1½}$ |
| 1601.400 | 3 | 62445.36 | |
| 1601.518 | 1 | 62440.76 | $4s\ ^4F_{3½} - 4p''\ ^2D^\circ_{2½}$ |
| 1601.742 | 4 | 62432.03 | $4p''\ ^4S^\circ_{1½} - 5d''\ ^4F_{1½}$ |
| 1601.928 | 10 | 62424.78 | $4p''\ ^4S^\circ_{1½} - 5d''\ ^4P_{0½}$ |
| 1602.209 | 12 | 62413.83 | $s^2\ ^4P_{1½} - t\ ^4D^\circ_{0½}$ |
| 1602.679 | 1 | 62395.53 | |
| 1602.973 | 20 | 62384.08 | $4s\ ^4F_{4½} - 4p''\ ^4D^\circ_{3½}$ |
| 1603.224 | 1 | 62374.32 | $4p\ ^4G^\circ_{4½} - 4d''\ ^4F_{4½}$ |
| 1603.410 | 20 | 62367.08 | $4s\ ^2F_{3½} - 4p'''\ ^2F^\circ_{3½}$ |
| 1603.555 | 25 | 62361.44 | |
| 1603.728 | 16 | 62354.71 | |
| 1603.917 | 5 | 62347.37 | $s^2\ ^4P_{2½} - 5f\ ^2D^\circ_{2½}$ |
| 1604.394 | 2 | 62328.83 | $s^2\ ^4P_{2½} - 5f\ ^4G^\circ_{3½}$ |
| 1604.482 | 18 | 62325.41 | |
| 1604.570 | 5 | 62321.99 | $4p\ ^4D^\circ_{1½} - 4d''\ ^4F_{2½}$ |
| 1604.696 | 3 | 62317.10 | $s^2\ ^4P_{2½} - 5f\ ^4D^\circ_{1½}$ |
| 1605.027 | 9 | 62304.25 | $s^2\ ^4P_{2½} - 5f\ ^4F^\circ_{2½}$ |
| 1605.217 | 4 | 62296.87 | |
| 1605.744 | 35 | 62276.43 | $s^2\ ^4F_{4½} - x\ ^4F^\circ_{4½}$ |
| 1605.795 | 3 | 62274.45 | |
| 1605.910 | 60 | 62269.99 | |
| 1606.280 | 12 | 62255.65 | |
| 1606.469 | 30 | 62248.32 | |
| 1606.695 | 8 | 62239.57 | $4p\ ^4F^\circ_{2½} - 6s\ ^4F_{2½}$ |
| 1606.729 | 15 | 62238.25 | |
| 1606.902 | 18 | 62231.55 | |
| 1607.477 | 1 | 62209.29 | |
| 1607.849 | 20 | 62194.90 | |
| 1607.987 | 3 | 62189.56 | |
| 1608.134 | 60 | 62183.87 | $s^2\ ^4F_{1½} - t\ ^2D^\circ_{1½}$ |
| 1608.177 | 80 | 62182.21 | $4s\ ^2G_{3½} - z\ ^4F^\circ_{3½}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 1608.244 | 4 | 62179.62 | |
| 1608.358 | 30 | 62175.21 | $s^2\,{}^4P_{1\frac{1}{2}} - t\,{}^4D^\circ_{1\frac{1}{2}}$ |
| 1608.442 | 25 | 62171.96 | $s^2\,{}^4F_{2\frac{1}{2}} - x\,{}^4G^\circ_{3\frac{1}{2}}$ |
| 1608.708 | 1 | 62161.68 | $4p'''\,{}^2F^\circ_{2\frac{1}{2}} - 9s\,{}^2F_{3\frac{1}{2}}$ |
| 1609.343 | 1 | 62137.16 | |
| 1609.474 | 12 | 62132.10 | $4p''\,{}^2D^\circ_{2\frac{1}{2}} - 5d'\,{}^2D_{1\frac{1}{2}}$ |
| 1610.102 | 20 | 62107.87 | $s^2\,{}^4P_{1\frac{1}{2}} - t\,{}^4D^\circ_{2\frac{1}{2}}$ |
| 1610.532 | 18 | 62091.28 | $4p''\,{}^2D^\circ_{2\frac{1}{2}} - 6s''\,{}^2P_{1\frac{1}{2}}$ |
| 1611.061 | 8 | 62070.90 | $s^2\,{}^4P_{1\frac{1}{2}} - 5f\,{}^2D^\circ_{2\frac{1}{2}}$ |
| 1611.079 | 6 | 62070.20 | $s^2\,{}^2G_{3\frac{1}{2}} - v\,{}^4F^\circ_{3\frac{1}{2}}$ |
| | | | $s^2\,{}^4F_{2\frac{1}{2}} - w\,{}^4D^\circ_{2\frac{1}{2}}$ |
| 1611.238 | 2 | 62064.08 | |
| 1611.390 | 25 | 62058.22 | |
| 1611.927 | 2 | 62037.55 | |
| 1612.163 | 1 | 62028.47 | |
| 1612.450 | 20 | 62017.43 | $s^2\,{}^4P_{1\frac{1}{2}} - 5f\,{}^2P^\circ_{1\frac{1}{2}}$ |
| 1613.132 | 2 | 61991.21 | $s^2\,{}^4F_{1\frac{1}{2}} - x\,{}^4F^\circ_{1\frac{1}{2}}$ |
| | | | $s^2\,{}^4P_{1\frac{1}{2}} - 5f\,{}^4P^\circ_{0\frac{1}{2}}$ |
| 1613.216 | 60 | 61987.98 | $s^2\,{}^2G_{3\frac{1}{2}} - w\,{}^2G^\circ_{4\frac{1}{2}}$ |
| 1613.820 | 20 | 61964.78 | $s^2\,{}^4F_{1\frac{1}{2}} - x\,{}^4G^\circ_{2\frac{1}{2}}$ |
| 1613.949 | 1 | 61959.83 | |
| 1614.218 | 2 | 61949.50 | |
| 1614.495 | 10 | 61938.87 | |
| 1614.824 | 30 | 61926.25 | |
| 1614.911 | 90 | 61922.92 | $4p\,{}^2G^\circ_{3\frac{1}{2}} - 6s\,{}^2F_{3\frac{1}{2}}$ |
| 1615.459 | 120 | 61901.91 | $s^2\,{}^4P_{2\frac{1}{2}} - t\,{}^4D^\circ_{3\frac{1}{2}}$ |
| 1615.704 | 9 | 61892.52 | |
| 1616.387 | 15 | 61866.37 | $4p''\,{}^2D^\circ_{1\frac{1}{2}} - 6s''\,{}^2P_{0\frac{1}{2}}$ |
| 1616.456 | 2 | 61863.73 | |
| 1616.536 | 25 | 61860.67 | $s^2\,{}^4P_{0\frac{1}{2}} - t\,{}^4D^\circ_{0\frac{1}{2}}$ |
| 1616.917 | 25 | 61846.09 | $s^2\,{}^4F_{3\frac{1}{2}} - x\,{}^4F^\circ_{3\frac{1}{2}}$ |
| 1616.993 | 2 | 61843.19 | $4p''\,{}^2D^\circ_{2\frac{1}{2}} - 6s''\,{}^4P_{1\frac{1}{2}}$ |
| 1617.088 | 50 | 61839.55 | |
| 1617.144 | 40 | 61837.41 | |
| 1617.299 | 40 | 61831.49 | $s^2\,{}^4F_{2\frac{1}{2}} - w\,{}^4D^\circ_{1\frac{1}{2}}$ |
| | | | $s^2\,{}^4P_{1\frac{1}{2}} - t\,{}^4D^\circ_{2\frac{1}{2}}$ |
| 1618.950 | 20 | 61768.43 | $s^2\,{}^2H_{5\frac{1}{2}} - w\,{}^2G^\circ_{4\frac{1}{2}}$ |
| 1619.193 | 1 | 61759.16 | $s^2\,{}^2P_{1\frac{1}{2}} - 4f''\,{}^4D^\circ_{1\frac{1}{2}}$ |
| 1619.395 | 6 | 61751.46 | $s^2\,{}^2G_{3\frac{1}{2}} - v\,{}^4F^\circ_{2\frac{1}{2}}$ |
| 1619.607 | 7 | 61743.37 | |
| 1619.857 | 20 | 61733.84 | |
| 1619.964 | 6 | 61729.77 | $s^2\,{}^2P_{1\frac{1}{2}} - 6f\,{}^2P^\circ_{1\frac{1}{2}}$ |
| 1619.989 | 5 | 61728.81 | |
| 1620.331 | 18 | 61715.79 | |
| 1620.428 | 1 | 61712.09 | $s^2\,{}^2G_{3\frac{1}{2}} - w\,{}^2F^\circ_{3\frac{1}{2}}$ |
| 1620.842 | 3 | 61696.33 | |
| 1620.946 | 1 | 61692.37 | $4p''\,{}^2D^\circ_{1\frac{1}{2}} - 5d'\,{}^2P_{1\frac{1}{2}}$ |
| 1621.460 | 40 | 61672.81 | $4p''\,{}^2D^\circ_{2\frac{1}{2}} - 6s''\,{}^4P_{2\frac{1}{2}}$? |
| 1621.880 | 6 | 61656.84 | $4p\ \ {}^4F^\circ_{3\frac{1}{2}} - 6s\ \ {}^4F_{3\frac{1}{2}}$ |
| 1621.926 | 18 | 61655.09 | $4s\,{}^4F_{2\frac{1}{2}} - 4p''\,{}^2D^\circ_{2\frac{1}{2}}$ |
| 1622.106 | 80 | 61648.25 | |
| 1622.164 | 2 | 61646.05 | |
| 1622.796 | 20 | 61622.04 | $s^2\,{}^4P_{0\frac{1}{2}} - t\,{}^4D^\circ_{1\frac{1}{2}}$ |
| 1622.923 | 1 | 61617.22 | |
| 1622.981 | 1 | 61615.02 | $4p\,{}^4D^\circ_{3\frac{1}{2}} - 4d'\,{}^2G_{4\frac{1}{2}}$ |
| 1624.084 | 60 | 61573.17 | $s^2\,{}^2G_{3\frac{1}{2}} - 4f'\,{}^2H^\circ_{4\frac{1}{2}}$ |
| 1624.172 | 20 | 61569.83 | $s^2\,{}^2G_{4\frac{1}{2}} - 7p\,{}^2G^\circ_{4\frac{1}{2}}$ |
| 1624.435 | 00 | 61559.87 | |
| 1624.773 | 16 | 61547.06 | $s^2\,{}^4F_{3\frac{1}{2}} - x\,{}^4G^\circ_{4\frac{1}{2}}$ |
| 1625.233 | 25 | 61529.64 | |
| 1625.288 | 2 | 61527.56 | $4p''\,{}^2D^\circ_{1\frac{1}{2}} - 5d'\,{}^2D_{1\frac{1}{2}}$ |
| 1626.161 | 12 | 61494.53 | |
| 1626.309 | 20 | 61488.93 | $s^2\,{}^2P_{1\frac{1}{2}} - w\,{}^2P^\circ_{1\frac{1}{2}}$ |
| 1626.320 | 15 | 61488.51 | |
| 1626.366 | 6 | 61486.77 | $4p''\,{}^2D^\circ_{1\frac{1}{2}} - 6s''\,{}^2P_{1\frac{1}{2}}$ |
| 1626.961 | 12 | 61464.29 | $s^2\,{}^4P_{0\frac{1}{2}} - 5f\,{}^2P^\circ_{1\frac{1}{2}}$ |
| 1627.396 | 12 | 61447.86 | $4s\,{}^4F_{3\frac{1}{2}} - 4p''\,{}^4D^\circ_{3\frac{1}{2}}$ |
| 1627.656 | 4 | 61438.04 | $4p\,{}^2D^\circ_{1\frac{1}{2}} - 5d\,{}^4D_{2\frac{1}{2}}$ |
| | | | $s^2\,{}^4P_{0\frac{1}{2}} - 5f\,{}^4P^\circ_{0\frac{1}{2}}$ |
| 1628.126 | 15 | 61420.31 | $4p''\,{}^4P^\circ_{2\frac{1}{2}} - 7s\,{}^4F_{3\frac{1}{2}}$ |
| 1628.497 | 10 | 61406.31 | $4s\,{}^2F_{2\frac{1}{2}} - 4p'''\,{}^2F^\circ_{2\frac{1}{2}}$ |
| 1628.726 | 15 | 61397.68 | |
| 1628.810 | 20 | 61394.51 | $s^2\,{}^2H_{5\frac{1}{2}} - 9p\,{}^4F^\circ_{4\frac{1}{2}}$ |
| 1629.282 | 100 | 61376.73 | $s^2\,{}^4F_{4\frac{1}{2}} - x\,{}^4G^\circ_{5\frac{1}{2}}$? |
| 1629.445 | 11 | 61370.59 | |
| 1629.591 | 70 | 61365.09 | $s^2\,{}^2P_{1\frac{1}{2}} - v\,{}^2D^\circ_{2\frac{1}{2}}$ |
| 1629.718 | 1 | 61360.31 | $s^2\,{}^2G_{3\frac{1}{2}} - 4f'\,{}^2G^\circ_{4\frac{1}{2}}$ |
| 1630.130 | 20 | 61344.80 | |
| 1630.356 | 10 | 61336.30 | |
| 1631.024 | 25 | 61311.18 | |
| 1631.182 | 12 | 61305.24 | $4s\,{}^4F_{3\frac{1}{2}} - 4p''\,{}^4D^\circ_{2\frac{1}{2}}$ |
| 1632.152 | 15 | 61268.80 | |
| 1632.171 | 30 | 61268.09 | $s^2\,{}^4F_{1\frac{1}{2}} - w\,{}^4D^\circ_{1\frac{1}{2}}$ |
| 1632.416 | 1 | 61258.89 | |
| 1632.488 | 6 | 61256.19 | $4p''\,{}^2P^\circ_{1\frac{1}{2}} - 6s''\,{}^2P_{0\frac{1}{2}}$ |
| 1632.960 | 2 | 61238.49 | $4p''\,{}^2D^\circ_{1\frac{1}{2}} - 6s''\,{}^4P_{1\frac{1}{2}}$ |
| 1633.189 | 4 | 61229.90 | |
| 1633.625 | 10 | 61213.56 | $4p\,{}^2F^\circ_{3\frac{1}{2}} - 6s\,{}^2F_{3\frac{1}{2}}$ |
| 1633.988 | 35 | 61199.96 | |
| 1635.070 | 30 | 61159.46 | |
| 1635.340 | 100 | 61149.36 | |
| 1636.068 | 1 | 61122.15 | |
| 1636.231 | 4 | 61116.06 | $s^2\,{}^4F_{3\frac{1}{2}} - x\,{}^4F^\circ_{4\frac{1}{2}}$ |
| 1636.488 | 3 | 61106.47 | $4p'\,{}^2D^\circ_{2\frac{1}{2}} - 6d\,{}^4D_{2\frac{1}{2}}$ |
| 1637.072 | 20 | 61084.67 | |
| 1637.140 | 2 | 61082.13 | $4p''\,{}^2P^\circ_{1\frac{1}{2}} - 5d'\,{}^2P_{1\frac{1}{2}}$ |
| 1637.267 | 10 | 61077.39 | |
| 1637.439 | 100 | 61070.98 | $s^2\,{}^2P_{1\frac{1}{2}} - w\,{}^2D^\circ_{1\frac{1}{2}}$ |
| 1637.509 | 20 | 61068.37 | $4p''\,{}^2D^\circ_{1\frac{1}{2}} - 6s''\,{}^4P_{2\frac{1}{2}}$ |
| 1637.589 | 300 | 61065.38 | $s^2\,{}^2G_{4\frac{1}{2}} - x\,{}^2H^\circ_{5\frac{1}{2}}$ |
| 1638.963 | 4 | 61014.19 | $4s^2\,{}^4F_{2\frac{1}{2}} - x\,{}^4F^\circ_{3\frac{1}{2}}$ |
| 1639.987 | 8 | 60976.09 | |
| 1640.769 | 7 | 60947.03 | $s^2\,{}^4P_{2\frac{1}{2}} - 5f\,{}^4D^\circ_{3\frac{1}{2}}$ |
| 1641.418 | 10 | 60922.93 | $s^2\,{}^4P_{2\frac{1}{2}} - 5f\,{}^4P^\circ_{2\frac{1}{2}}$ |
| 1642.299 | 20 | 60890.25 | |
| 1642.324 | 40 | 60889.32 | $s^2\,{}^2P_{1\frac{1}{2}} - w\,{}^2D^\circ_{2\frac{1}{2}}$ |
| 1642.351 | 15 | 60888.32 | |
| 1642.670 | 5 | 60876.50 | $4p''\,{}^2P^\circ_{1\frac{1}{2}} - 6s''\,{}^2P_{1\frac{1}{2}}$ |
| 1642.739 | 2 | 60873.94 | $4p\,{}^2D^\circ_{2\frac{1}{2}} - 6s\,{}^2F_{3\frac{1}{2}}$ |
| 1642.792 | 2 | 60871.98 | $4p''\,{}^2P^\circ_{1\frac{1}{2}} - 6s''\,{}^4P_{0\frac{1}{2}}$ |
| 1643.271 | 80 | 60854.24 | $s^2\,{}^2G_{3\frac{1}{2}} - x\,{}^2H^\circ_{4\frac{1}{2}}$ |
| 1643.334 | 20 | 60851.90 | $s^2\,{}^4P_{2\frac{1}{2}} - 5f\,{}^4S^\circ_{1\frac{1}{2}}$ |
| 1644.040 | 14 | 60825.77 | |
| 1644.137 | 6 | 60822.18 | $4p\,{}^2F^\circ_{2\frac{1}{2}} - 6s\,{}^2F_{2\frac{1}{2}}$ |
| 1645.654 | 0 | 60766.11 | $4p\,{}^4D^\circ_{0\frac{1}{2}} - 4d''\,{}^4D_{1\frac{1}{2}}$ |
| 1647.637 | 10 | 60692.98 | |
| 1648.353 | 3 | 60666.62 | |
| 1648.381 | 1 | 60665.59 | $s^2\,{}^4P_{1\frac{1}{2}} - 5f\,{}^4P^\circ_{1\frac{1}{2}}$ |
| 1649.396 | 13 | 60628.25 | $4p''\,{}^2P^\circ_{1\frac{1}{2}} - 6s''\,{}^4P_{1\frac{1}{2}}$ |
| 1649.905 | 3 | 60609.55 | $4p\,{}^2D^\circ_{1\frac{1}{2}} - 6s\,{}^2F_{2\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II — Continued

| λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 1650.412 | 14 | 60590.93 | $4s\ ^4F_{2\frac{1}{2}} - 4p''\ ^4D^\circ_{1\frac{1}{2}}$ |
| 1650.636 | 4 | 60582.71 | |
| 1650.835 | 10 | 60575.41 | $s^2\ ^4P_{1\frac{1}{2}} - 5f\ ^4S^\circ_{1\frac{1}{2}}$ |
| 1652.270 | 13 | 60522.80 | |
| 1652.355 | 3 | 60519.68 | $4s\ ^4F_{2\frac{1}{2}} - 4p''\ ^4D^\circ_{2\frac{1}{2}}$ |
| 1652.477 | 3 | 60515.21 | |
| 1652.726 | 10 | 60506.10 | |
| 1652.839 | 15 | 60501.96 | |
| 1653.369 | 18 | 60482.57 | |
| 1653.687 | 10 | 60470.94 | $s^2\ ^2G_{3\frac{1}{2}} - 7p\ ^2G^\circ_{4\frac{1}{2}}$ |
| 1653.779 | 10 | 60467.57 | |
| 1654.667 | 1 | 60435.12 | |
| 1655.749 | 1 | 60395.63 | |
| 1655.903 | 0 | 60390.01 | $s^2\ ^2P_{1\frac{1}{2}} - s\ ^4D^\circ_{0\frac{1}{2}}$ |
| 1656.840 | 3 | 60355.86 | $s^2\ ^2P_{1\frac{1}{2}} - 6f\ ^4P^\circ_{1\frac{1}{2}}$ |
| 1657.273 | 2 | 60340.09 | |
| 1657.313 | 10 | 60338.63 | $4p''\ ^2P^\circ_{0\frac{1}{2}} - 6s''\ ^2P_{0\frac{1}{2}}$ |
| 1661.018 | 20 | 60204.04 | |
| 1662.063 | 3 | 60166.19 | |
| 1662.423 | 20 | 60153.16 | |
| 1662.892 | 25 | 60136.20 | |
| 1663.563 | 16 | 60111.94 | $s^2\ ^2G_{4\frac{1}{2}} - l\ ^2G^\circ_{4\frac{1}{2}}$ |
| 1664.316 | 10 | 60084.74 | $4s\ ^4F_{1\frac{1}{2}} - 4p''\ ^4D^\circ_{0\frac{1}{2}}$ |
| 1664.384 | 2 | 60082.29 | $4p'''\ ^2G^\circ_{4\frac{1}{2}} - 6s'''\ ^2G_{4\frac{1}{2}}$ |
| 1664.459 | 8 | 60079.58 | $s^2\ ^2P_{1\frac{1}{2}} - s\ ^4D^\circ_{2\frac{1}{2}}$ |
| 1665.477 | 4 | 60042.86 | $4s\ ^4F_{1\frac{1}{2}} - 4p''\ ^4D^\circ_{1\frac{1}{2}}$ |
| 1665.860 | 1 | 60029.05 | |
| 1666.045 | 0 | 60022.39 | $s^2\ ^4P_{0\frac{1}{2}} - 5f\ ^4S^\circ_{1\frac{1}{2}}$ |
| 1666.828 | 4 | 59994.19 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 6s\ ^4F_{3\frac{1}{2}}$ |
| 1667.930 | 4 | 59954.55 | $4p''\ ^2P^\circ_{0\frac{1}{2}} - 6s''\ ^4P_{0\frac{1}{2}}$ |
| 1668.122 | 1 | 59947.65 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 4d'\ ^2F_{2\frac{1}{2}}$ |
| 1670.935 | 7 | 59846.73 | $s^2\ ^2G_{4\frac{1}{2}} - 5f\ ^2H^\circ_{5\frac{1}{2}}$ |
| 1671.514 | 12 | 59826.00 | $s^2\ ^2H_{4\frac{1}{2}} - 8p\ ^2G^\circ_{3\frac{1}{2}}$ |
| 1674.000 | 10 | 59737.16 | $4s\ ^4F_{4\frac{1}{2}} - 4p'\ ^2F^\circ_{3\frac{1}{2}}$ |
| 1676.317 | 3 | 59654.59 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 6s\ ^4F_{3\frac{1}{2}}$ |
| 1676.671 | 2 | 59641.99 | |
| 1677.297 | 1 | 59619.73 | $4p''\ ^2S^\circ_{0\frac{1}{2}} - 5d'\ ^2D_{1\frac{1}{2}}$ |
| 1678.447 | 5 | 59578.88 | $4p''\ ^2S^\circ_{0\frac{1}{2}} - 6s''\ ^2P_{1\frac{1}{2}}$ |
| 1678.476 | 10 | 59577.85 | $s^2\ ^4F_{3\frac{1}{2}} - y\ ^4G^\circ_{3\frac{1}{2}}$ |
| 1678.941 | 1 | 59561.35 | $4p''\ ^4S^\circ_{1\frac{1}{2}} - 6s''\ ^2P_{1\frac{1}{2}}$ |
| 1679.068 | 7 | 59556.85 | $4p''\ ^4S^\circ_{1\frac{1}{2}} - 6s''\ ^4P_{0\frac{1}{2}}$ |
| 1684.952 | 70 | 59348.87 | $s^2\ ^2H_{5\frac{1}{2}} - v\ ^2G^\circ_{4\frac{1}{2}}$ |
| 1685.465 | 8 | 59330.81 | $4p''\ ^2S^\circ_{0\frac{1}{2}} - 6s''\ ^4P_{1\frac{1}{2}}$ |
| 1685.965 | 9 | 59313.21 | $4p''\ ^4S^\circ_{1\frac{1}{2}} - 6s''\ ^4P_{1\frac{1}{2}}$ |
| 1686.934 | 9 | 59279.14 | |
| 1690.814 | 12 | 59143.11 | $4p''\ ^4S^\circ_{1\frac{1}{2}} - 6s''\ ^4P_{2\frac{1}{2}}$ |
| 1691.231 | 11 | 59128.53 | |
| 1693.177 | 10 | 59060.57 | $s^2\ ^2D_{2\frac{1}{2}} - 6p'\ ^2F^\circ_{3\frac{1}{2}}$ |
| 1694.384 | 2 | 59018.50 | $s^2\ ^2P_{1\frac{1}{2}} - 4f'\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1695.594 | 8 | 58976.38 | $s^2\ ^4F_{4\frac{1}{2}} - y\ ^4G^\circ_{4\frac{1}{2}}$ |
| 1695.897 | 1 | 58965.84 | |
| 1696.527 | 2 | 58943.95 | |
| 1698.400 | 4 | 58878.94 | |
| 1699.772 | 2 | 58831.42 | |
| 1700.665 | 1 | 58800.53 | $s^2\ ^4F_{4\frac{1}{2}} - y\ ^4F^\circ_{3\frac{1}{2}}$ |
| 1701.504 | 2 | 58771.53 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 4d''\ ^2F_{2\frac{1}{2}}$ |
| 1702.150 | 1 | 58749.23 | |
| 1702.265 | 7 | 58745.26 | $s^2\ ^4F_{2\frac{1}{2}} - y\ ^4G^\circ_{3\frac{1}{2}}$? |
| 1703.408 | 25 | 58705.84 | $3d\ ^2D_{2\frac{1}{2}} - 4p\ ^2D^\circ_{1\frac{1}{2}}$ |
| 1705.581 | 11 | 58631.05 | |
| 1705.739 | 8 | 58625.62 | |
| 1706.170 | 2 | 58610.81 | |
| 1708.386 | 25 | 58534.78 | $s^2\ ^2H_{5\frac{1}{2}} - 8p\ ^4G^\circ_{4\frac{1}{2}}$ |
| 1708.570 | 1 | 58528.48 | |
| 1709.598 | 200 | 58493.28 | $3d\ ^2D_{2\frac{1}{2}} - 4p\ ^2F^\circ_{2\frac{1}{2}}$ |
| 1710.032 | 3 | 58478.44 | $s^2\ ^2G_{4\frac{1}{2}} - 5f\ ^4F^\circ_{5\frac{1}{2}}$ |
| 1713.285 | 2 | 58367.40 | $s^2\ ^4F_{3\frac{1}{2}} - y\ ^4F^\circ_{2\frac{1}{2}}$ |
| 1716.148 | 1 | 58270.03 | |
| 1717.700 | 3 | 58217.38 | $s^2\ ^2H_{4\frac{1}{2}} - 4f''\ ^4D^\circ_{3\frac{1}{2}}$ |
| 1719.906 | 5 | 58142.71 | $s^2\ ^2H_{4\frac{1}{2}} - 4f''\ ^4G^\circ_{3\frac{1}{2}}$ |
| 1721.092 | 15 | 58102.65 | $s^2\ ^4F_{4\frac{1}{2}} - y\ ^4F^\circ_{4\frac{1}{2}}$ |
| 1722.113 | 1 | 58068.20 | $s^2\ ^2D_{2\frac{1}{2}} - 4f'''\ ^2F^\circ_{3\frac{1}{2}}$ |
| 1722.646 | 2 | 58050.23 | $s^2\ ^2D_{2\frac{1}{2}} - w\ ^2P^\circ_{1\frac{1}{2}}$ |
| 1723.859 | 20 | 58009.38 | $s^2\ ^2H_{4\frac{1}{2}} - v\ ^2G^\circ_{3\frac{1}{2}}$ |
| 1723.957 | 1 | 58006.09 | |
| 1724.818 | 1 | 57977.13 | |
| 1726.324 | 4 | 57926.55 | $s^2\ ^2D_{2\frac{1}{2}} - v\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1728.022 | 1 | 57869.63 | |
| 1728.133 | 2 | 57865.92 | |
| 1728.625 | 6 | 57849.45 | |
| 1732.620 | 1 | 57716.06 | |
| 1734.904 | 8 | 57640.08 | $s^2\ ^4F_{3\frac{1}{2}} - y\ ^4F^\circ_{3\frac{1}{2}}$ |
| 1735.135 | 5 | 57632.40 | $s^2\ ^2D_{2\frac{1}{2}} - w\ ^2D^\circ_{1\frac{1}{2}}$ |
| 1738.059 | 3 | 57535.45 | $s^2\ ^4F_{2\frac{1}{2}} - y\ ^4F^\circ_{2\frac{1}{2}}$ |
| 1738.311 | 12 | 57527.10 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 6d\ ^4D_{3\frac{1}{2}}$ |
| 1738.549 | 1 | 57519.23 | $s^2\ ^4F_{1\frac{1}{2}} - y\ ^4F^\circ_{1\frac{1}{2}}$ |
| 1738.793 | 4 | 57511.16 | $s^2\ ^2H_{5\frac{1}{2}} - 6f\ ^4F^\circ_{6\frac{1}{2}}$ |
| 1740.619 | 30 | 57450.83 | $s^2\ ^2D_{2\frac{1}{2}} - w\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1741.547 | 1000 | 57420.21 | $3d\ ^2D_{2\frac{1}{2}} - 4p\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1746.989 | 1 | 57241.34 | $4s\ ^4F_{3\frac{1}{2}} - 4p''\ ^4P^\circ_{2\frac{1}{2}}$ |
| 1748.285 | 500 | 57198.91 | $3d\ ^2D_{1\frac{1}{2}} - 4p\ ^2D^\circ_{1\frac{1}{2}}$ |
| 1751.911 | 300 | 57080.52 | $3d\ ^2D_{2\frac{1}{2}} - 4p\ ^2F^\circ_{3\frac{1}{2}}$ |
| 1754.808 | 50 | 56986.29 | $3d\ ^2D_{1\frac{1}{2}} - 4p\ ^2F^\circ_{2\frac{1}{2}}$ |
| 1756.829 | 2 | 56920.74 | |
| 1763.097 | 1 | 56718.38 | $s^2\ ^2H_{5\frac{1}{2}} - w\ ^2G^\circ_{4\frac{1}{2}}$ |
| 1769.940 | 2 | 56499.09 | $s^2\ ^2G_{4\frac{1}{2}} - 5p'''\ ^2H^\circ_{5\frac{1}{2}}$ |
| 1771.865 | 4 | 56437.71 | $s^2\ ^2G_{3\frac{1}{2}} - 5p'''\ ^2G^\circ_{3\frac{1}{2}}$ |
| 1772.197 | 1 | 56427.13 | $s^2\ ^2D_{1\frac{1}{2}} - w\ ^2P^\circ_{1\frac{1}{2}}$ |
| 1773.949 | 25 | 56371.41 | $3d\ ^2D_{2\frac{1}{2}} - 4p\ ^2G^\circ_{3\frac{1}{2}}$ |
| 1783.317 | 1 | 56075.28 | $3d\ ^2D_{2\frac{1}{2}} - 4p\ ^4F^\circ_{2\frac{1}{2}}$ |
| 1788.485 | 100 | 55913.24 | $3d\ ^2D_{1\frac{1}{2}} - 4p\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1789.640 | 1 | 55877.16 | |
| 1791.219 | 1 | 55827.90 | $s^2\ ^2D_{1\frac{1}{2}} - w\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1804.451 | 1 | 55418.52 | |
| 1804.473 | 30 | 55417.84 | $3d\ ^2D_{2\frac{1}{2}} - 4p\ ^4F^\circ_{3\frac{1}{2}}$ |
| 1808.330 | 2 | 55299.64 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 4d'\ ^2F_{3\frac{1}{2}}$ |
| 1812.065 | 30 | 55185.66 | $4s\ ^2F_{3\frac{1}{2}} - 4p'\ ^2D^\circ_{2\frac{1}{2}}$ |
| 1817.112 | 1 | 55032.38 | |
| 1820.916 | 1 | 54917.42 | $3d\ ^2D_{1\frac{1}{2}} - 4p\ ^4F^\circ_{1\frac{1}{2}}$ |
| 1825.068 | 1 | 54792.48 | $s^2\ ^4F_{4\frac{1}{2}} - 5p\ ^2F^\circ_{3\frac{1}{2}}$ |
| 1832.144 | 1 | 54580.86 | $4s\ ^2F_{3\frac{1}{2}} - 4p'\ ^2F^\circ_{3\frac{1}{2}}$ |
| 1832.566 | 1 | 54568.29 | $3d\ ^2D_{1\frac{1}{2}} - 4p\ ^4F^\circ_{2\frac{1}{2}}$ |
| 1833.403 | 5 | 54543.38 | $s^2\ ^4F_{4\frac{1}{2}} - 5p\ ^2G^\circ_{4\frac{1}{2}}$ |
| 1837.744 | 1 | 54414.54 | $s^2\ ^4F_{3\frac{1}{2}} - 5p\ ^2G^\circ_{3\frac{1}{2}}$ |
| 1837.985 | 2 | 54407.41 | |
| 1842.889 | 1 | 54262.63 | $3d\ ^2D_{2\frac{1}{2}} - 4p\ ^4G^\circ_{3\frac{1}{2}}$ |
| 1852.522 | 2 | 53980.47 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 4d'\ ^2F_{2\frac{1}{2}}$ |
| 1852.875 | 2 | 53970.18 | $4s\ ^2F_{2\frac{1}{2}} - 4p'\ ^2P^\circ_{1\frac{1}{2}}$ |
| 1857.587 | 6 | 53833.28 | |
| 1860.689 | 1 | 53743.53 | $s^2\ ^2H_{5\frac{1}{2}} - 7p\ ^4F^\circ_{4\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II — Continued

| λ(vac) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 1860.796 | 1 | 53740.44 | $4s\,^2F_{2\frac{1}{2}} - 4p'\,^2D^\circ_{2\frac{1}{2}}$ |
| 1864.558 | 6 | 53632.01 | $s^2\,^4F_{3\frac{1}{2}} - 5p\,^2F^\circ_{3\frac{1}{2}}$ |
| 1865.637 | 5 | 53601.00 | $s^2\,^4F_{4\frac{1}{2}} - 5p\,^4F^\circ_{3\frac{1}{2}}$ |
| 1866.499 | 5 | 53576.24 | $s^2\,^4P_{2\frac{1}{2}} - 5p''\,^4S^\circ_{1\frac{1}{2}}$ |
| 1870.460 | 8 | 53462.78 | $s^2\,^4F_{3\frac{1}{2}} - 5p\,^4F^\circ_{2\frac{1}{2}}$ |
| 1875.069 | 3 | 53331.37 | $s^2\,^4F_{2\frac{1}{2}} - 5p\,^4F^\circ_{1\frac{1}{2}}$ |
| 1876.180 | 1 | 53299.79 | $s^2\,^4P_{1\frac{1}{2}} - 5p''\,^4S^\circ_{1\frac{1}{2}}$ |
| 1876.418 | 2 | 53293.03 | $s^2\,^4F_{3\frac{1}{2}} - 5p\,^4G^\circ_{3\frac{1}{2}}$ |
| 1877.838 | 40 | 53252.73 | $s^2\,^4F_{4\frac{1}{2}} - 5p\,^4G^\circ_{4\frac{1}{2}}$ |
| 1878.103 | 2 | 53245.22 | $s^2\,^4F_{2\frac{1}{2}} - 5p\,^4G^\circ_{2\frac{1}{2}}$ |
| 1881.155 | 25 | 53158.83 | $4s\,^2F_{2\frac{1}{2}} - 4p'\,^2D^\circ_{1\frac{1}{2}}$ |
| 1883.170 | 4 | 53101.95 | $s^2\,^4F_{4\frac{1}{2}} - 5p\,^4G^\circ_{5\frac{1}{2}}$ |
| 1885.525 | 20 | 53035.63 | $s^2\,^4F_{4\frac{1}{2}} - 5p\,^4F^\circ_{4\frac{1}{2}}$ |
| 1886.043 | 12 | 53021.06 | $4s\,^2F_{3\frac{1}{2}} - 4p''\,^4P^\circ_{2\frac{1}{2}}$ |
| 1893.600 | 1 | 52809.46 | $4s'\,^2D_{2\frac{1}{2}} - 4p'''\,^2F^\circ_{3\frac{1}{2}}$ |
| 1895.082 | 6 | 52768.17 | $s^2\,^4F_{1\frac{1}{2}} - 5p\,^4F^\circ_{1\frac{1}{2}}$ |
| 1896.147 | 2 | 52738.53 | $3d\,^2D_{2\frac{1}{2}} - 4p\,^4D^\circ_{2\frac{1}{2}}$ |
| 1900.025 | 4 | 52630.89 | $s^2\,^4F_{2\frac{1}{2}} - 5p\,^4F^\circ_{2\frac{1}{2}}$ |
| 1900.865 | 15 | 52607.63 | $s^2\,^4F_{4\frac{1}{2}} - 5p\,^4D^\circ_{3\frac{1}{2}}$ |
| 1900.921 | 2 | 52606.08 | $4s'\,^2D_{1\frac{1}{2}} - 4p'''\,^2F^\circ_{2\frac{1}{2}}$ |
| 1907.612 | 1 | 52421.56 | $s^2\,^4F_{1\frac{1}{2}} - 5p\,^4D^\circ_{0\frac{1}{2}}$ |
| 1908.326 | 1 | 52401.95 | $s^2\,^4F_{2\frac{1}{2}} - 5p\,^4D^\circ_{1\frac{1}{2}}$ |
| 1912.146 | 2 | 52297.26 | $s^2\,^4F_{3\frac{1}{2}} - 5p\,^4D^\circ_{2\frac{1}{2}}$ |
| 1920.582 | 1 | 52067.55 | $s^2\,^4F_{1\frac{1}{2}} - 5p\,^4F^\circ_{2\frac{1}{2}}$ |
| 1927.707 | 2 | 51875.10 | $s^2\,^4F_{3\frac{1}{2}} - 5p\,^4F^\circ_{4\frac{1}{2}}$ |
| 1929.063 | 1 | 51838.64 | $s^2\,^4F_{1\frac{1}{2}} - 5p\,^4D^\circ_{1\frac{1}{2}}$ |
| 1930.493 | 1 | 51800.24 | |
| 1937.661 | 1 | 51608.61 | $s^2\,^4F_{2\frac{1}{2}} - 5p\,^4F^\circ_{3\frac{1}{2}}$ |
| 1938.579 | 2 | 51584.18 | $4s\,^2F_{2\frac{1}{2}} - 4p''\,^4P^\circ_{1\frac{1}{2}}$ |
| 1939.901 | 10 | 51549.02 | |
| 1943.060 | 2 | 51465.21 | $s^2\,^4F_{2\frac{1}{2}} - 5p\,^4D^\circ_{2\frac{1}{2}}$ |
| 1943.744 | 2 | 51447.10 | $s^2\,^4F_{3\frac{1}{2}} - 5p\,^4D^\circ_{3\frac{1}{2}}$ |
| 1953.407 | 40 | 51192.61 | $4s'\,^2D_{2\frac{1}{2}} - 4p''\,^4S^\circ_{1\frac{1}{2}}$ |
| 1954.709 | 1 | 51158.51 | $s^2\,^2H_{5\frac{1}{2}} - 5p'''\,^2G^\circ_{4\frac{1}{2}}$ |
| 1965.357 | 8 | 50881.34 | $4s''\,^4P_{2\frac{1}{2}} - 4p'''\,^2F^\circ_{3\frac{1}{2}}$ |
| 1980.010 | 15 | 50504.80 | $4s'\,^2D_{1\frac{1}{2}} - 4p''\,^4S^\circ_{1\frac{1}{2}}$ |
| 1980.699 | 3 | 50487.23 | $4s'\,^2D_{1\frac{1}{2}} - 4p''\,^2S^\circ_{0\frac{1}{2}}$ |
| 1993.570 | 2 | 50161.27 | $4p''\,^4P^\circ_{2\frac{1}{2}} - 4d''\,^4P_{2\frac{1}{2}}$ |
| 1993.906 | 1 | 50152.82 | $4p''\,^4P^\circ_{1\frac{1}{2}} - 4d''\,^4P_{2\frac{1}{2}}$ |
| 1995.723 | 15 | 50107.15 | $4s'\,^2D_{1\frac{1}{2}} - 4p''\,^2P^\circ_{0\frac{1}{2}}$ |
| 2004.123 | 3 | 49897.14 | $4p''\,^4P^\circ_{2\frac{1}{2}} - 4d''\,^2D_{1\frac{1}{2}}$ |
| 2004.460 | 1 | 49888.75 | $4p''\,^4P^\circ_{1\frac{1}{2}} - 4d''\,^2D_{1\frac{1}{2}}$ |
| 2004.914 | 50 | 49877.45 | $4s'\,^2D_{2\frac{1}{2}} - 4p''\,^2P^\circ_{1\frac{1}{2}}$ |
| 2010.411 | 2 | 49741.07 | $4p''\,^4P^\circ_{2\frac{1}{2}} - 4d''\,^4P_{1\frac{1}{2}}$ |
| 2012.797 | 4 | 49682.11 | $4p''\,^4P^\circ_{1\frac{1}{2}} - 4d''\,^4P_{0\frac{1}{2}}$ |
| 2015.648 | 2 | 49611.84 | $4p''\,^4P^\circ_{1\frac{1}{2}} - 4d''\,^2F_{2\frac{1}{2}}$ |
| 2019.683 | 50 | 49512.72 | $4s''\,^4P_{1\frac{1}{2}} - 4p''\,^4S^\circ_{1\frac{1}{2}}$ |
| 2020.399 | 5 | 49495.17 | $4s''\,^4P_{1\frac{1}{2}} - 4p''\,^2S^\circ_{0\frac{1}{2}}$ |
| 2021.632 | 50 | 49464.99 | $4s''\,^4P_{0\frac{1}{2}} - 4p''\,^4S^\circ_{1\frac{1}{2}}$ |
| 2028.787 | 3 | 49290.54 | $4p''\,^4P^\circ_{1\frac{1}{2}} - 4d''\,^2D_{2\frac{1}{2}}$ |
| 2029.165 | 6 | 49281.35 | $4p''\,^4P^\circ_{0\frac{1}{2}} - 4d''\,^4P_{1\frac{1}{2}}$ |
| 2029.750 | 2 | 49267.15 | $4s'\,^2D_{2\frac{1}{2}} - 4p''\,^2D^\circ_{1\frac{1}{2}}$ |
| 2029.859 | 50 | 49264.51 | $4s''\,^4P_{2\frac{1}{2}} - 4p''\,^4S^\circ_{1\frac{1}{2}}$ |
| 2032.957 | 25 | 49189.43 | $4s'\,^2D_{1\frac{1}{2}} - 4p''\,^2P^\circ_{1\frac{1}{2}}$ |
| 2034.045 | 3 | 49163.12 | $4s\,^4F_{3\frac{1}{2}} - 4p\,^2F^\circ_{2\frac{1}{2}}$ |
| 2036.040 | 2 | 49114.95 | $4s''\,^4P_{1\frac{1}{2}} - 4p''\,^2P^\circ_{0\frac{1}{2}}$ |
| 2038.264 | 2 | 49061.36 | $4p\,^4D^\circ_{3\frac{1}{2}} - 4d\,^2G_{4\frac{1}{2}}$ |

## TABLE I. *Lines of* Ni II

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 2050.355 | 1 | 48756.42 | |
| 2053.300 | 5 | 48686.50 | $4s\ ^4F_{4\frac{1}{2}} - 4p\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2054.313 | 20 | 48662.49 | $4s'\ ^2D_{2\frac{1}{2}} - 4p''\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2055.579 | 1 | 48632.52 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 4d''\ ^2P_{0\frac{1}{2}}$ |
| 2057.376 | 1 | 48590.05 | $4s\ ^4F_{2\frac{1}{2}} - 4p\ ^2D^\circ_{1\frac{1}{2}}$ |
| 2057.480 | 0 | 48587.60 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 5s'\ ^2D_{2\frac{1}{2}}$ |
| 2057.838 | 1 | 48579.14 | $4s'\ ^2D_{1\frac{1}{2}} - 4p''\ ^2D^\circ_{1\frac{1}{2}}$ |
| 2060.820 | 0 | 48508.86 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 4d\ ^2F_{2\frac{1}{2}}$ |
| 2064.225 | 2 | 48428.85 | |
| 2066.417 | 3 | 48377.49 | $4s\ ^4F_{2\frac{1}{2}} - 4p\ ^2F^\circ_{2\frac{1}{2}}$ |
| 2067.049 | 5 | 48362.70 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 4d''\ ^4D_{1\frac{1}{2}}$ |
| 2069.130 | 1 | 48314.06 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^2D_{1\frac{1}{2}}$ |
| 2069.579 | 6 | 48303.58 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 4d''\ ^4D_{2\frac{1}{2}}$ |
| 2069.940 | 18 | 48295.16 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 4d''\ ^4D_{2\frac{1}{2}}$ |
| 2071.220 | 30 | 48265.32 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 4d''\ ^4D_{3\frac{1}{2}}$ |
| 2074.138 | 1 | 48197.43 | $4s''\ ^4P_{1\frac{1}{2}} - 4p''\ ^2P^\circ_{1\frac{1}{2}}$ |
| 2078.016 | 3 | 48107.49 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 4d''\ ^4P_{0\frac{1}{2}}$ |
| 2079.174 | 30 | 48080.70 | |
| 2080.850 | 20 | 48041.98 | $4s\ ^4F_{1\frac{1}{2}} - 4p\ ^2D^\circ_{1\frac{1}{2}}$ |
| 2081.338 | 2 | 48030.72 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 4d''\ ^4P_{1\frac{1}{2}}$ |
| 2082.605 | 4 | 48001.50 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 4d\ ^4D_{2\frac{1}{2}}$ |
| 2083.649 | 1 | 47977.45 | $4s\ ^4F_{4\frac{1}{2}} - 4p\ ^2G^\circ_{3\frac{1}{2}}$ |
| 2083.770 | 5 | 47974.67 | $4s'\ ^2D_{1\frac{1}{2}} - 4p''\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2084.875 | 30 | 47949.24 | $4s''\ ^4P_{2\frac{1}{2}} - 4p''\ ^2P^\circ_{1\frac{1}{2}}$ |
| 2085.315 | 25 | 47939.13 | $4p''\ ^4P^\circ_{0\frac{1}{2}} - 4d''\ ^4D_{0\frac{1}{2}}$ |
| 2085.654 | 50 | 47931.34 | |
| 2086.519 | 20 | 47911.47 | $4p''\ ^4P^\circ_{0\frac{1}{2}} - 4d''\ ^4D_{1\frac{1}{2}}$ |
| 2087.672 | 7 | 47885.01 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 4d\ ^4G_{4\frac{1}{2}}$ |
| 2088.212 | 1 | 47872.63 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^2P_{1\frac{1}{2}}$ |
| 2089.000 | 35 | 47854.57 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 4d\ ^4G_{3\frac{1}{2}}$ |
| 2090.103 | 15 | 47829.32 | $4s\ ^4F_{1\frac{1}{2}} - 4p\ ^2F^\circ_{2\frac{1}{2}}$ |
| 2092.142 | 3 | 47782.71 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 4d\ ^4F_{3\frac{1}{2}}$ |
| 2092.840 | 3 | 47766.78 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^4P_{2\frac{1}{2}}$ |
| 2093.466 | 15 | 47752.50 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 4d\ ^4D_{1\frac{1}{2}}$ |
| 2093.555 | 20 | 47750.47 | $4s\ ^4F_{3\frac{1}{2}} - 4p\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2094.128 | 15 | 47737.40 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 4d\ ^2F_{3\frac{1}{2}}$ |
| 2094.348 | 1 | 47732.39 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d''\ ^2D_{1\frac{1}{2}}$ |
| 2094.388 | 7 | 47731.48 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^4G_{2\frac{1}{2}}$ |
| 2095.852 | 1 | 47698.14 | $4p'''\ ^2H^\circ_{4\frac{1}{2}} - 4d'''\ ^2G_{3\frac{1}{2}}$ |
| 2096.305 | 0 | 47687.81 | $4p'''\ ^2H^\circ_{4\frac{1}{2}} - 4d'''\ ^2G_{4\frac{1}{2}}$ |
| 2097.094 | 200 | 47669.90 | $4s'\ ^2D_{2\frac{1}{2}} - 4p''\ ^4D^\circ_{3\frac{1}{2}}$ |
| 2098.368 | 10 | 47640.96 | $4p'''\ ^2H^\circ_{4\frac{1}{2}} - 4d'''\ ^2H_{4\frac{1}{2}}$ |
| 2099.150 | 0 | 47623.21 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^4F_{1\frac{1}{2}}$? |
| 2099.614 | 12 | 47612.69 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^2F_{2\frac{1}{2}}$ |
| 2099.668 | 6 | 47611.46 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^2P_{0\frac{1}{2}}$ |
| 2099.925 | 13 | 47605.64 | |
| 2100.240 | 3 | 47598.50 | $4s'\ ^2D_{2\frac{1}{2}} - 4p''\ ^4D^\circ_{1\frac{1}{2}}$ |
| 2100.308 | 60 | 47596.96 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 4d\ ^4F_{4\frac{1}{2}}$ |
| 2101.218 | 3 | 47576.35 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d''\ ^4P_{1\frac{1}{2}}$ |
| 2102.849 | 1 | 47539.45 | $4s''\ ^2P_{0\frac{1}{2}} - 4p''\ ^2D^\circ_{1\frac{1}{2}}$ |
| 2103.392 | 20 | 47527.18 | $4s'\ ^2D_{2\frac{1}{2}} - 4p''\ ^4D^\circ_{2\frac{1}{2}}$ |
| 2106.937 | 0 | 47447.22 | |
| 2107.826 | 1 | 47427.21 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 5s'\ ^2D_{1\frac{1}{2}}$ |
| 2107.954 | 200 | 47424.33 | $4s'''\ ^2G_{4\frac{1}{2}} - 4p'''\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2109.023 | 18 | 47400.30 | $4s'''\ ^2G_{3\frac{1}{2}} - 4p'''\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2111.418 | 2 | 47346.54 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^4P_{1\frac{1}{2}}$ |
| 2112.450 | 50 | 47323.41 | $4s'''\ ^2G_{4\frac{1}{2}} - 4p'''\ ^2G^\circ_{3\frac{1}{2}}$ |
| 2113.300 | 0 | 47304.38 | $4s\ ^4F_{2\frac{1}{2}} - 4p\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2113.579 | 300 | 47298.13 | $4s'''\ ^2G_{3\frac{1}{2}} - 4p'''\ ^2G^\circ_{3\frac{1}{2}}$ |
| 2113.674 | 4 | 47296.01 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^4P_{0\frac{1}{2}}$ |
| 2115.176 | 3 | 47262.43 | |
| 2116.228 | 0 | 47238.94 | $4p\ ^4F^\circ_{1\frac{1}{2}} - 4d\ ^2D_{1\frac{1}{2}}$ |
| 2116.818 | 1 | 47225.77 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^2F_{2\frac{1}{2}}$ |
| 2117.494 | 1 | 47210.70 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^4D_{0\frac{1}{2}}$ |
| 2118.863 | 2 | 47180.20 | $4p'\ ^2F^\circ_{2\frac{1}{2}} - 4d''\ ^4D_{2\frac{1}{2}}$ |
| 2120.582 | 6 | 47141.96 | $4p'\ ^2F^\circ_{2\frac{1}{2}} - 4d''\ ^4D_{3\frac{1}{2}}$ |
| 2120.915 | 0 | 47134.56 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d''\ ^2D_{2\frac{1}{2}}$ |
| 2121.769 | 1 | 47115.59 | $4p'''\ ^2H^\circ_{5\frac{1}{2}} - 4d'''\ ^2G_{4\frac{1}{2}}$ |
| 2121.995 | 0 | 47110.57 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 4d\ ^2F_{3\frac{1}{2}}$ |
| 2122.474 | 25 | 47099.94 | $4p'''\ ^2H^\circ_{5\frac{1}{2}} - 4d'''\ ^2H_{5\frac{1}{2}}$ |
| 2122.590 | 2 | 47097.36 | |
| 2122.720 | 0 | 47094.48 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 4d\ ^2H_{4\frac{1}{2}}$ |
| 2123.298 | 50 | 47081.66 | $4p\ ^4D^\circ_{0\frac{1}{2}} - 4d\ ^4F_{1\frac{1}{2}}$ |
| 2123.836 | 3 | 47069.74 | $4p\ ^4D^\circ_{0\frac{1}{2}} - 4d\ ^2P_{0\frac{1}{2}}$ |
| 2125.030 | 10 | 47043.29 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 4d'\ ^2S_{0\frac{1}{2}}$ |
| 2125.122 | 40 | 47041.26 | $4s\ ^4F_{3\frac{1}{2}} - 4p\ ^2G^\circ_{3\frac{1}{2}}$ |
| | | | $6s\ ^4F_{4\frac{1}{2}} - 6p''\ ^4D^\circ_{3\frac{1}{2}}$ |
| 2125.914 | 25 | 47023.73 | $4s\ ^4F_{4\frac{1}{2}} - 4p\ ^4F^\circ_{3\frac{1}{2}}$ |
| 2126.838 | 300 | 47003.31 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 4d\ ^4P_{2\frac{1}{2}}$ |
| 2127.685 | 1 | 46984.60 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 4d\ ^2F_{2\frac{1}{2}}$ |
| 2127.777 | 40 | 46982.57 | $4s''\ ^4P_{1\frac{1}{2}} - 4p''\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2128.583 | 70 | 46964.78 | $4s\ ^4F_{2\frac{1}{2}} - 4p\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2129.061 | 1 | 46954.23 | $4p'\ ^2F^\circ_{3\frac{1}{2}} - 5s'''\ ^2G_{3\frac{1}{2}}$ |
| 2129.141 | 3 | 46952.47 | $4s'\ ^2D_{1\frac{1}{2}} - 4p''\ ^4D^\circ_{0\frac{1}{2}}$ |
| 2129.523 | 8 | 46944.05 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 4d\ ^2H_{5\frac{1}{2}}$ |
| 2130.172 | 0 | 46929.75 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 4d'''\ ^2G_{3\frac{1}{2}}$ |
| 2130.628 | 3 | 46919.71 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 4d'''\ ^2G_{4\frac{1}{2}}$ |
| 2131.046 | 60 | 46910.50 | $4s'\ ^2D_{1\frac{1}{2}} - 4p''\ ^4D^\circ_{1\frac{1}{2}}$ |
| 2131.099 | 300 | 46909.34 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 4d\ ^4D_{3\frac{1}{2}}$ |
| 2131.265 | 35 | 46905.68 | $4s\ ^4F_{4\frac{1}{2}} - 4p\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2131.370 | 1 | 46903.37 | |
| 2132.353 | 1 | 46881.75 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 4d\ ^4H_{3\frac{1}{2}}$? |
| 2133.517 | 50 | 46856.18 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^4D_{1\frac{1}{2}}$ |
| 2134.289 | 50 | 46839.23 | $4s'\ ^2D_{1\frac{1}{2}} - 4p''\ ^4D^\circ_{2\frac{1}{2}}$ |
| 2134.375 | 10 | 46837.35 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 4d'\ ^2P_{1\frac{1}{2}}$ |
| 2134.441 | 15 | 46835.90 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 4d'\ ^2D_{2\frac{1}{2}}$ |
| 2134.760 | 20 | 46828.90 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 4d'\ ^2P_{1\frac{1}{2}}$ |
| 2135.127 | 250 | 46820.85 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 4d\ ^4D_{2\frac{1}{2}}$ |
| 2136.622 | 10 | 46788.09 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 4d''\ ^4D_{1\frac{1}{2}}$ |
| 2138.143 | 25 | 46754.81 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^4F_{2\frac{1}{2}}$ |
| 2138.582 | 50 | 46745.22 | $4s\ ^4F_{3\frac{1}{2}} - 4p\ ^4F^\circ_{2\frac{1}{2}}$ |
| 2139.085 | 0 | 46734.23 | $4s''\ ^4P_{2\frac{1}{2}} - 4p''\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2139.668 | 1 | 46721.49 | $4p\ ^4G^\circ_{2\frac{1}{2}} - 4d\ ^2G_{3\frac{1}{2}}$ |
| 2139.710 | 20 | 46720.58 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 4d''\ ^4D_{2\frac{1}{2}}$ |
| 2141.184 | 12 | 46688.42 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 4d''\ ^4D_{0\frac{1}{2}}$ |
| 2142.069 | 40 | 46669.13 | $4p\ ^4D^\circ_{0\frac{1}{2}} - 4d\ ^4D_{0\frac{1}{2}}$ |
| 2142.453 | 3 | 46660.77 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 4d''\ ^4D_{1\frac{1}{2}}$ |
| 2143.165 | 20 | 46645.27 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 4d'\ ^2P_{0\frac{1}{2}}$ |
| 2144.958 | 1 | 46606.28 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 4d'\ ^2G_{3\frac{1}{2}}$ |
| 2145.152 | 30 | 46602.07 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 4d\ ^4F_{3\frac{1}{2}}$ |
| 2145.609 | 2 | 46592.14 | $4p''\ ^4P^\circ_{0\frac{1}{2}} - 5d'\ ^2S_{0\frac{1}{2}}$ |
| 2152.381 | 4 | 46445.57 | $4p'''\ ^2F^\circ_{2\frac{1}{2}} - 4d'''\ ^2G_{3\frac{1}{2}}$ |
| 2152.449 | 16 | 46444.10 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^2P_{1\frac{1}{2}}$ |
| 2155.635 | 35 | 46375.46 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^4P_{0\frac{1}{2}}$ |
| 2156.512 | 8 | 46356.61 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 4d\ ^2G_{4\frac{1}{2}}$ |
| 2156.941 | 25 | 46347.39 | $4p\ ^4G^\circ_{2\frac{1}{2}} - 4d\ ^4G_{2\frac{1}{2}}$ |
| 2157.490 | 1 | 46335.59 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 4d'\ ^2D_{1\frac{1}{2}}$ |
| 2157.736 | 18 | 46330.31 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 4d\ ^4G_{3\frac{1}{2}}$ |
| 2157.882 | 20 | 46327.18 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 4d'\ ^2D_{1\frac{1}{2}}$ |
| 2158.467 | 5 | 46314.62 | $4p\ ^4D^\circ_{0\frac{1}{2}} - 4d\ ^4D_{1\frac{1}{2}}$ |
| 2158.741 | 50 | 46308.75 | $4s\ ^4F_{3\frac{1}{2}} - 4p\ ^4F^\circ_{1\frac{1}{2}}$ |
| 2159.043 | 100 | 46302.27 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 4d\ ^4P_{1\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II — Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 2159.698 | 25 | 46288.23 | $4p'''\,^2H^\circ_{4\frac{1}{2}} - 4d'''\,^2\,I_{5\frac{1}{2}}$ |
| 2161.217 | 80 | 46255.70 | $4s\,^4F_{2\frac{1}{2}} - 4p\,^2G^\circ_{3\frac{1}{2}}$ |
| 2161.792 | 18 | 46243.40 | $4p\,^2D^\circ_{2\frac{1}{2}} - 4d\,^2D_{1\frac{1}{2}}$ |
| 2161.984 | 11 | 46239.29 | $4p\,^4G^\circ_{2\frac{1}{2}} - 4d\,^4F_{1\frac{1}{2}}$ |
| 2162.481 | 18 | 46228.66 | $4p\,^4G^\circ_{2\frac{1}{2}} - 4d\,^2F_{2\frac{1}{2}}$ |
| 2163.208 | 50 | 46213.13 | $4p\,^4G^\circ_{3\frac{1}{2}} - 4d\,^2F_{3\frac{1}{2}}$ |
| 2163.521 | 1 | 46206.44 | $4p'\,^2D^\circ_{2\frac{1}{2}} - 4d''\,^4D_{1\frac{1}{2}}$ |
| 2164.102 | 10 | 46194.04 | $4p''\,^4P^\circ_{0\frac{1}{2}} - 4d'\,^2P_{0\frac{1}{2}}$ |
| 2165.278 | 30 | 46168.95 | $4p'''\,^2F^\circ_{3\frac{1}{2}} - 4d'''\,^2F_{3\frac{1}{2}}$ |
| 2165.553 | 1000 | 46163.09 | $4s\,^4F_{4\frac{1}{2}} - 4p\,^4F^\circ_{4\frac{1}{2}}$ |
| 2166.242 | 70 | 46148.41 | $4p''\,^4P^\circ_{2\frac{1}{2}} - 4d'\,^2F_{3\frac{1}{2}}$ |
| 2166.688 | 25 | 46138.91 | $4p'\,^2D^\circ_{2\frac{1}{2}} - 4d''\,^4D_{2\frac{1}{2}}$ |
| 2167.256 | 30 | 46126.82 | $4p\,^4G^\circ_{3\frac{1}{2}} - 4d\,^4F_{2\frac{1}{2}}$ |
| 2167.299 | 150 | 46125.91 | $4p\,^4G^\circ_{2\frac{1}{2}} - 4d\,^4H_{3\frac{1}{2}}$ |
| 2167.815 | 50 | 46114.93 | $4p''\,^4P^\circ_{2\frac{1}{2}} - 4d'\,^2F_{2\frac{1}{2}}$ |
| 2168.212 | 50 | 46106.48 | $4p''\,^4P^\circ_{1\frac{1}{2}} - 4d'\,^2F_{2\frac{1}{2}}$ |
| 2168.486 | 80 | 46100.66 | $4p'\,^2D^\circ_{2\frac{1}{2}} - 4d''\,^4D_{3\frac{1}{2}}$ |
| 2169.096 | 2000 | 46087.70 | $4s\,^4F_{3\frac{1}{2}} - 4p\,^4F^\circ_{3\frac{1}{2}}$ |
| 2169.569 | 40 | 46077.65 | $4p\,^4G^\circ_{4\frac{1}{2}} - 4d\,^4G_{4\frac{1}{2}}$ |
| 2169.955 | 300 | 46069.45 | $4p\,^4G^\circ_{3\frac{1}{2}} - 4d\,^4H_{4\frac{1}{2}}$ |
| 2174.119 | 6 | 45981.23 | |
| 2174.331 | 10 | 45976.75 | $4p'\,^2P^\circ_{1\frac{1}{2}} - 4d''\,^4D_{1\frac{1}{2}}$ |
| 2174.396 | 30 | 45975.37 | $4p\,^4G^\circ_{4\frac{1}{2}} - 4d\,^4F_{3\frac{1}{2}}$ |
| 2174.666 | 2000 | 45969.66 | $4s\,^4F_{3\frac{1}{2}} - 4p\,^2G^\circ_{3\frac{1}{2}}$ |
| 2175.147 | 1500 | 45959.50 | $4s\,^4F_{2\frac{1}{2}} - 4p\,^4F^\circ_{2\frac{1}{2}}$ |
| 2175.832 | 30 | 45945.03 | $4p\,^2F^\circ_{3\frac{1}{2}} - 4d\,^2D_{2\frac{1}{2}}$ |
| 2176.101 | 7 | 45939.35 | $4p''\,^2D^\circ_{1\frac{1}{2}} - 6s\,^4F_{2\frac{1}{2}}$<br>$4p\,^4F^\circ_{3\frac{1}{2}} - 4d\,^2H_{4\frac{1}{2}}$ |
| 2176.796 | 2 | 45924.69 | $4p\,^4D^\circ_{1\frac{1}{2}} - 4d\,^4D_{2\frac{1}{2}}$ |
| 2177.086 | 500 | 45918.57 | $4s''\,^4P_{1\frac{1}{2}} - 4p''\,^4D^\circ_{1\frac{1}{2}}$ |
| 2177.361 | 400 | 45912.77 | $4s''\,^4P_{0\frac{1}{2}} - 4p''\,^4D^\circ_{0\frac{1}{2}}$ |
| 2177.531 | 25 | 45909.19 | $4p'\,^2P^\circ_{1\frac{1}{2}} - 4d''\,^4D_{2\frac{1}{2}}$ |
| 2177.847 | 25 | 45902.53 | $4p\,^4D^\circ_{0\frac{1}{2}} - 4d\,^2P_{1\frac{1}{2}}$ |
| 2179.110 | 12 | 45875.93 | $4p''\,^4P^\circ_{0\frac{1}{2}} - 4d'\,^2D_{1\frac{1}{2}}$ |
| 2179.352 | 400 | 45870.83 | $4s''\,^4P_{0\frac{1}{2}} - 4p''\,^4D_{1\frac{1}{2}}$ |
| 2179.453 | 20 | 45868.71 | $4s\,^4F_{4\frac{1}{2}} - 4p\,^4G^\circ_{3\frac{1}{2}}$ |
| 2179.990 | 50 | 45857.41 | $4s'\,^2D_{2\frac{1}{2}} - 4p'\,^2P^\circ_{1\frac{1}{2}}$ |
| 2180.473 | 800 | 45847.25 | $4s''\,^4P_{1\frac{1}{2}} - 4p''\,^4D^\circ_{2\frac{1}{2}}$ |
| 2181.135 | 1 | 45833.34 | |
| 2183.217 | 80 | 45789.63 | $4p\,^4G^\circ_{4\frac{1}{2}} - 4d\,^4F_{4\frac{1}{2}}$ |
| 2184.268 | 7 | 45767.60 | $5p\,^4G^\circ_{4\frac{1}{2}} - 5d\,^4G_{5\frac{1}{2}}$ |
| 2184.605 | 800 | 45760.54 | $4s\,^4F_{1\frac{1}{2}} - 4p\,^4F^\circ_{1\frac{1}{2}}$ |
| 2184.875 | 35 | 45754.89 | $4p'''\,^2H^\circ_{5\frac{1}{2}} - 4d'''\,^2\,I_{6\frac{1}{2}}$ |
| 2185.504 | 2500 | 45741.72 | $4s''\,^4P_{2\frac{1}{2}} - 4p''\,^4D^\circ_{3\frac{1}{2}}$ |
| 2186.120 | 20 | 45728.84 | $4p\,^4D^\circ_{2\frac{1}{2}} - 4d\,^4D_{3\frac{1}{2}}$ |
| 2186.893 | 18 | 45712.67 | $4p'\,^2F^\circ_{2\frac{1}{2}} - 4d'\,^2D_{2\frac{1}{2}}$ |
| 2187.315 | 25 | 45703.85 | $s^2\,^2F_{3\frac{1}{2}} - u\,^2G^\circ_{4\frac{1}{2}}$ |
| 2187.696 | 2 | 45695.90 | |
| 2188.045 | 25 | 45688.61 | $4s\,^4F_{3\frac{1}{2}} - 4p\,^4G^\circ_{2\frac{1}{2}}$ |
| 2188.541 | 25 | 45678.25 | $4p'''\,^2F^\circ_{2\frac{1}{2}} - 4d'''\,^2F_{2\frac{1}{2}}$ |
| 2188.918 | 2 | 45670.39 | $4s''\,^4P_{2\frac{1}{2}} - 4p''\,^4D^\circ_{1\frac{1}{2}}$ |
| 2189.174 | 4 | 45665.05 | $4p\,^4F^\circ_{2\frac{1}{2}} - 4d\,^2G_{3\frac{1}{2}}$ |
| 2189.498 | 45 | 45658.29 | $4p\,^4G^\circ_{5\frac{1}{2}} - 4d\,^4F_{4\frac{1}{2}}$ |
| 2190.557 | 80 | 45636.22 | $4p\,^4G^\circ_{5\frac{1}{2}} - 4d\,^4G_{5\frac{1}{2}}$ |
| 2190.967 | 30 | 45627.68 | $4s'\,^2D_{2\frac{1}{2}} - 4p'\,^2D^\circ_{2\frac{1}{2}}$ |
| 2192.036 | 100 | 45605.43 | $4p\,^2D^\circ_{2\frac{1}{2}} - 4d\,^2D_{2\frac{1}{2}}$ |
| 2192.090 | 3000 | 45604.31 | $4p\,^4G^\circ_{4\frac{1}{2}} - 4d\,^4H_{5\frac{1}{2}}$ |
| 2192.341 | 150 | 45599.09 | $4s''\,^4P_{2\frac{1}{2}} - 4p''\,^4D^\circ_{2\frac{1}{2}}$ |
| 2193.009 | 1 | 45585.20 | |
| 2193.534 | 50 | 45574.29 | $4p\,^4G^\circ_{2\frac{1}{2}} - 4d\,^4G_{3\frac{1}{2}}$ |
| 2197.854 | 25 | 45484.72 | $4p''\,^4D^\circ_{1\frac{1}{2}} - 5d''\,^2F_{2\frac{1}{2}}$ |
| 2197.936 | 200 | 45483.03 | $4p'\,^2F^\circ_{2\frac{1}{2}} - 4d'\,^2G_{3\frac{1}{2}}$ |
| 2198.423 | 120 | 45472.95 | $4p\,^4G^\circ_{5\frac{1}{2}} - 4d\,^4H_{5\frac{1}{2}}$ |
| 2199.188 | 20 | 45457.13 | $4p\,^4G^\circ_{2\frac{1}{2}} - 4d\,^2F_{3\frac{1}{2}}$ |
| 2201.028 | 25 | 45419.14 | $4p''\,^4D^\circ_{0\frac{1}{2}} - 4d''\,^4F_{1\frac{1}{2}}$ |
| 2201.409 | 600 | 45411.28 | $4s\,^4F_{1\frac{1}{2}} - 4p\,^4F^\circ_{2\frac{1}{2}}$ |
| 2203.068 | 40 | 45377.08 | $4p'''\,^2F^\circ_{3\frac{1}{2}} - 5d\,^2G_{4\frac{1}{2}}$ |
| 2203.373 | 25 | 45370.80 | $4p\,^4G^\circ_{2\frac{1}{2}} - 4d\,^4F_{2\frac{1}{2}}$ |
| 2203.468 | 60 | 45368.85 | $4p\,^2G^\circ_{3\frac{1}{2}} - 4d\,^2G_{3\frac{1}{2}}$ |
| 2204.799 | 10 | 45341.46 | $4p'\,^2P^\circ_{0\frac{1}{2}} - 4d'\,^2S_{0\frac{1}{2}}$ |
| 2205.548 | 5000 | 45326.07 | $4p\,^4G^\circ_{5\frac{1}{2}} - 4d\,^4H_{6\frac{1}{2}}$ |
| 2205.783 | 20 | 45321.24 | $4p''\,^4D^\circ_{2\frac{1}{2}} - 4d''\,^4F_{2\frac{1}{2}}$ |
| 2205.866 | 80 | 45319.53 | $4p\,^2G^\circ_{4\frac{1}{2}} - 4d\,^2G_{4\frac{1}{2}}$ |
| 2206.321 | 5 | 45310.19 | $4p'''\,^2F^\circ_{3\frac{1}{2}} - 5d\,^4F_{2\frac{1}{2}}$ |
| 2206.715 | 4000 | 45302.10 | $4s\,^4F_{2\frac{1}{2}} - 4p\,^4F^\circ_{3\frac{1}{2}}$ |
| 2206.961 | 20 | 45297.05 | $4p'''\,^2F^\circ_{2\frac{1}{2}} - 5d\,^4D_{1\frac{1}{2}}$ |
| 2206.981 | 30 | 45296.64 | $4p\,^4G^\circ_{3\frac{1}{2}} - 4d\,^4D_{2\frac{1}{2}}$ |
| 2207.148 | 1 | 45293.21 | $4p\,^2G^\circ_{4\frac{1}{2}} - 4d\,^4G_{3\frac{1}{2}}$ |
| 2207.262 | 20 | 45290.87 | $4p\,^4F^\circ_{2\frac{1}{2}} - 4d\,^4G_{2\frac{1}{2}}$ |
| 2209.040 | 1 | 45254.42 | $4p'\,^2D^\circ_{1\frac{1}{2}} - 4d'\,^2P_{1\frac{1}{2}}$ |
| 2209.111 | 25 | 45252.97 | $4p'\,^2D^\circ_{1\frac{1}{2}} - 4d'\,^2D_{2\frac{1}{2}}$ |
| 2209.260 | 50 | 45249.92 | $4p''\,^4D^\circ_{1\frac{1}{2}} - 4d''\,^4F_{2\frac{1}{2}}$ |
| 2210.001 | 20 | 45234.75 | $4p''\,^4D^\circ_{2\frac{1}{2}} - 4d''\,^2D_{2\frac{1}{2}}$ |
| 2210.238 | 6 | 45229.90 | $4s''\,^2P_{1\frac{1}{2}} - 4p''\,^4S^\circ_{1\frac{1}{2}}$ |
| 2210.382 | 300 | 45226.95 | $4s\,^4F_{3\frac{1}{2}} - 4p\,^4F^\circ_{4\frac{1}{2}}$ |
| 2211.097 | 300 | 45212.33 | $4s''\,^2P_{1\frac{1}{2}} - 4p''\,^2S^\circ_{0\frac{1}{2}}$ |
| 2211.630 | 25 | 45201.43 | $4p'\,^2F^\circ_{2\frac{1}{2}} - 4d'\,^2D_{1\frac{1}{2}}$<br>$4p\,^4F^\circ_{3\frac{1}{2}} - 4d\,^2G_{4\frac{1}{2}}$ |
| 2212.109 | 150 | 45191.64 | $4p''\,^4D^\circ_{2\frac{1}{2}} - 4d''\,^4F_{3\frac{1}{2}}$ |
| 2212.673 | 50 | 45180.13 | $4p\,^4G^\circ_{3\frac{1}{2}} - 4d\,^4G_{4\frac{1}{2}}$ |
| 2212.872 | 20 | 45176.06 | $4p\,^2G^\circ_{4\frac{1}{2}} - 4d\,^2F_{3\frac{1}{2}}$ |
| 2212.917 | 40 | 45175.15 | $4p\,^4F^\circ_{3\frac{1}{2}} - 4d\,^4G_{3\frac{1}{2}}$ |
| 2213.066 | 12 | 45172.10 | $4p\,^4F^\circ_{2\frac{1}{2}} - 4d\,^2F_{2\frac{1}{2}}$ |
| 2213.155 | 50 | 45170.29 | $4p\,^2F^\circ_{2\frac{1}{2}} - 4d\,^2D_{1\frac{1}{2}}$ |
| 2213.196 | 150 | 45169.45 | $4s'\,^2D_{1\frac{1}{2}} - 4p'\,^2P^\circ_{1\frac{1}{2}}$ |
| 2213.489 | 1 | 45163.47 | $4p''\,^4D^\circ_{1\frac{1}{2}} - 4d''\,^2D_{2\frac{1}{2}}$ |
| 2214.895 | 20 | 45134.81 | |
| 2215.275 | 6 | 45127.06 | $4p'\,^2P^\circ_{0\frac{1}{2}} - 4d'\,^2P_{1\frac{1}{2}}$ |
| 2216.482 | 6000 | 45102.49 | $4s\,^4F_{4\frac{1}{2}} - 4p\,^4G^\circ_{5\frac{1}{2}}$ |
| 2217.695 | 40 | 45077.83 | $4p\,^4G^\circ_{3\frac{1}{2}} - 4d\,^4F_{3\frac{1}{2}}$ |
| 2218.045 | 5 | 45070.71 | $4p'\,^2D^\circ_{1\frac{1}{2}} - 4d'\,^2P_{0\frac{1}{2}}$ |
| 2218.111 | 150 | 45069.37 | $4p\,^4F^\circ_{2\frac{1}{2}} - 4d\,^4H_{3\frac{1}{2}}$ |
| 2218.207 | 1 | 45067.42 | $4p''\,^2D^\circ_{2\frac{1}{2}} - 4d''\,^2P_{1\frac{1}{2}}$ |
| 2218.573 | 2 | 45059.99 | $4p\,^4G^\circ_{2\frac{1}{2}} - 4d\,^2P_{1\frac{1}{2}}$ |
| 2219.116 | 20 | 45048.96 | $4p''\,^4D^\circ_{3\frac{1}{2}} - 4d''\,^4F_{3\frac{1}{2}}$ |
| 2219.246 | 1 | 45046.33 | $4p'\,^2F_{3\frac{1}{2}} - 4d'\,^2G_{3\frac{1}{2}}$ |
| 2219.472 | 200 | 45041.74 | $4p'\,^2F^\circ_{3\frac{1}{2}} - 4d'\,^2G_{4\frac{1}{2}}$ |
| 2219.936 | 2 | 45032.33 | $4p\,^2G^\circ_{4\frac{1}{2}} - 4d\,^4H_{4\frac{1}{2}}$ |
| 2220.402 | 800 | 45022.87 | $4s'\,^2D_{2\frac{1}{2}} - 4p'\,^2F^\circ_{3\frac{1}{2}}$ |
| 2221.062 | 500 | 45009.50 | $4p\,^2G^\circ_{4\frac{1}{2}} - 4d\,^2H_{5\frac{1}{2}}$ |
| 2221.759 | 25 | 44995.38 | |
| 2222.236 | 120 | 44985.72 | $4p\,^2G^\circ_{3\frac{1}{2}} - 4d\,^2H_{4\frac{1}{2}}$ |
| 2222.957 | 900 | 44971.13 | $4s\,^4F_{4\frac{1}{2}} - 4p\,^4G^\circ_{4\frac{1}{2}}$ |
| 2223.455 | 300 | 44961.06 | $4p''\,^4D^\circ_{3\frac{1}{2}} - 4d''\,^4F_{4\frac{1}{2}}$ |
| 2223.619 | 15 | 44957.75 | $4p\,^2D^\circ_{1\frac{1}{2}} - 4d\,^2D_{1\frac{1}{2}}$ |
| 2224.327 | 5 | 44943.44 | $4p'\,^2P^\circ_{0\frac{1}{2}} - 4d'\,^2P_{0\frac{1}{2}}$ |
| 2224.355 | 10 | 44942.87 | $4s\,^2F_{3\frac{1}{2}} - 4p\,^2F^\circ_{2\frac{1}{2}}$ |
| 2224.414 | 15 | 44941.68 | $4p\,^4F^\circ_{1\frac{1}{2}} - 4d\,^4G_{2\frac{1}{2}}$ |
| 2224.504 | 5 | 44939.86 | $4s'\,^2D_{1\frac{1}{2}} - 4p'\,^2D^\circ_{2\frac{1}{2}}$ |
| 2224.864 | 200 | 44932.59 | $4s\,^4F_{3\frac{1}{2}} - 4p\,^4G^\circ_{3\frac{1}{2}}$ |
| 2225.768 | 50 | 44914.34 | $4p\,^4F^\circ_{3\frac{1}{2}} - 4d\,^4H_{4\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II — Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 2226.329 | 100 | 44903.03 | $4s\ ^4F_{2\frac{1}{2}} - 4p\ ^4G^\circ_{2\frac{1}{2}}$ |
| 2226.866 | 5 | 44892.20 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 4d\ ^4F_{4\frac{1}{2}}$ |
| 2227.186 | 40 | 44885.75 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 4d\ ^4G_{4\frac{1}{2}}$ |
| 2227.672 | 15 | 44875.96 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 4d\ ^2F_{2\frac{1}{2}}$ |
| 2229.776 | 50 | 44833.62 | $4p\ ^4F^\circ_{1\frac{1}{2}} - 4d\ ^4F_{1\frac{1}{2}}$ |
| 2230.308 | 2 | 44822.92 | $4p\ ^4F^\circ_{1\frac{1}{2}} - 4d\ ^2F_{2\frac{1}{2}}$ |
| 2230.368 | 2 | 44821.72 | $4p\ ^4F^\circ_{1\frac{1}{2}} - 4d\ ^2P_{0\frac{1}{2}}$ |
| 2233.809 | 20 | 44752.68 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 4d'\ ^2D_{1\frac{1}{2}}$ |
| 2235.758 | 8 | 44713.67 | $4p'''\ ^2F^\circ_{2\frac{1}{2}} - 5d\ ^2P_{1\frac{1}{2}}$ |
| 2236.063 | 3 | 44707.57 | $4s''\ ^2P_{0\frac{1}{2}} - 4p''\ ^4S^\circ_{1\frac{1}{2}}$ |
| 2236.566 | 8 | 44697.52 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 4d''\ ^2D_{1\frac{1}{2}}$ |
| 2236.984 | 2 | 44689.17 | $4s''\ ^2P_{0\frac{1}{2}} - 4p''\ ^2S^\circ_{0\frac{1}{2}}$ |
| 2237.161 | 1 | 44685.63 | |
| 2237.803 | 5 | 44672.81 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d'\ ^2P_{1\frac{1}{2}}$ |
| 2237.876 | 20 | 44671.36 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d'\ ^2D_{2\frac{1}{2}}$ |
| 2238.033 | 2 | 44668.22 | |
| 2238.452 | 20 | 44659.86 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 4d\ ^2G_{3\frac{1}{2}}$ |
| 2238.572 | 15 | 44657.47 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 4d'\ ^2S_{0\frac{1}{2}}$ |
| 2239.999 | 20 | 44629.02 | |
| 2240.185 | 15 | 44625.32 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 4d'\ ^2D_{1\frac{1}{2}}$ |
| 2241.571 | 200 | 44597.73 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 4d\ ^4F_{4\frac{1}{2}}$ |
| 2242.031 | 100 | 44588.58 | $4p'\ ^2F^\circ_{3\frac{1}{2}} - 4d'\ ^2F_{3\frac{1}{2}}$ |
| 2242.141 | 2 | 44586.39 | $4s'\ ^2D_{2\frac{1}{2}} - 4p'\ ^2F^\circ_{2\frac{1}{2}}$ |
| 2242.680 | 500 | 44575.68 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 4d\ ^4G_{5\frac{1}{2}}$ |
| 2243.715 | 10 | 44555.12 | $4p'\ ^2F^\circ_{3\frac{1}{2}} - 4d'\ ^2F_{2\frac{1}{2}}$ |
| 2244.858 | 60 | 44532.43 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^2D_{2\frac{1}{2}}$ |
| 2244.878 | 30 | 44532.04 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 4d'\ ^2F_{2\frac{1}{2}}$ |
| 2245.596 | 20 | 44517.80 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 4d\ ^4G_{3\frac{1}{2}}$ |
| 2246.611 | 2 | 44497.69 | |
| 2247.228 | 100 | 44485.47 | $4s'\ ^2D_{1\frac{1}{2}} - 4p'\ ^2P^\circ_{0\frac{1}{2}}$ |
| 2248.369 | 15 | 44462.90 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 4d''\ ^2P_{1\frac{1}{2}}$ |
| 2249.027 | 0 | 44449.89 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 5s'''\ ^2G_{3\frac{1}{2}}$ |
| 2249.371 | 15 | 44443.09 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 4d'\ ^2P_{1\frac{1}{2}}$ |
| 2249.444 | 30 | 44441.65 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 4d'\ ^2D_{2\frac{1}{2}}$<br>$4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d'\ ^2G_{3\frac{1}{2}}$ |
| 2250.488 | 10 | 44421.04 | $4p\ ^4F^\circ_{1\frac{1}{2}} - 4d\ ^4D_{0\frac{1}{2}}$ |
| 2250.508 | 20 | 44420.64 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 4d''\ ^2F_{2\frac{1}{2}}$ |
| 2250.755 | 10 | 44415.77 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 4d\ ^4D_{1\frac{1}{2}}$ |
| 2250.920 | 3 | 44412.51 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 4d\ ^4H_{5\frac{1}{2}}$ |
| 2250.998 | 3 | 44410.97 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 4d''\ ^2P_{0\frac{1}{2}}$ |
| 2251.520 | 30 | 44400.68 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 4d\ ^2F_{3\frac{1}{2}}$ |
| 2252.830 | 200 | 44374.86 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 4d''\ ^2F_{3\frac{1}{2}}$ |
| 2253.679 | 50 | 44358.15 | $4s'\ ^2D_{1\frac{1}{2}} - 4p'\ ^2D^\circ_{1\frac{1}{2}}$ |
| 2253.734 | 25? | 44357.06 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 4d''\ ^4P_{2\frac{1}{2}}$ |
| 2253.848 | 500 | 44354.82 | $4s\ ^4F_{1\frac{1}{2}} - 4p\ ^4G^\circ_{2\frac{1}{2}}$ |
| 2254.258 | 8 | 44346.76 | |
| 2255.612 | 15 | 44320.14 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^2G_{3\frac{1}{2}}$ |
| 2255.632 | 30 | 44319.75 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^2D_{2\frac{1}{2}}$ |
| 2255.908 | 50 | 44314.32 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 4d\ ^4F_{2\frac{1}{2}}$ |
| 2256.137 | 75 | 44309.83 | $4s''\ ^2P_{1\frac{1}{2}} - 4p''\ ^2P^\circ_{0\frac{1}{2}}$ |
| 2256.279 | 3 | 44307.04 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 4d''\ ^4D_{1\frac{1}{2}}$ |
| 2256.708 | 5 | 44298.61 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 4d\ ^4P_{2\frac{1}{2}}$ |
| 2257.826 | 200 | 44276.68 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 4d\ ^2H_{4\frac{1}{2}}$ |
| 2258.504 | 5 | 44263.39 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 4d''\ ^4D_{0\frac{1}{2}}$ |
| 2258.704 | 3 | 44259.47 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 4d'\ ^2P_{0\frac{1}{2}}$ |
| 2259.294 | 200 | 44247.92 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 4d\ ^2G_{4\frac{1}{2}}$ |
| 2259.726 | 10 | 44239.46 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 4d''\ ^4D_{2\frac{1}{2}}$ |
| 2259.917 | 10 | 44235.72 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 4d''\ ^4D_{1\frac{1}{2}}$ |
| 2260.383 | 50 | 44226.60 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 5d\ ^4D_{2\frac{1}{2}}$ |
| 2260.644 | 30 | 44221.49 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 4d\ ^2G_{3\frac{1}{2}}$<br>$4p''\ ^4D^\circ_{0\frac{1}{2}} - 4d''\ ^4D_{0\frac{1}{2}}$ |
| 2261.685 | 5 | 44201.14 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 4d''\ ^4D_{3\frac{1}{2}}$ |
| 2262.066 | 10 | 44193.70 | $4p''\ ^4D^\circ_{0\frac{1}{2}} - 4d''\ ^4D_{1\frac{1}{2}}$ |
| 2262.459 | 2 | 44186.02 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 4d''\ ^4F_{2\frac{1}{2}}$? |
| 2262.898 | 30 | 44177.45 | $4s''\ ^4P_{1\frac{1}{2}} - 4p'\ ^2P^\circ_{1\frac{1}{2}}$ |
| 2263.375 | 3 | 44168.14 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 4d''\ ^4D_{2\frac{1}{2}}$ |
| 2263.443 | 5 | 44166.81 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 4d\ ^2F_{2\frac{1}{2}}$ |
| 2264.461 | 1000 | 44146.96 | $4s\ ^4F_{2\frac{1}{2}} - 4p\ ^4G^\circ_{3\frac{1}{2}}$ |
| 2264.739 | 50 | 44141.54 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 4d\ ^4D_{2\frac{1}{2}}$ |
| 2265.345 | 30 | 44129.74 | $4s''\ ^4P_{0\frac{1}{2}} - 4p'\ ^2P^\circ_{1\frac{1}{2}}$ |
| 2266.647 | 30 | 44104.39 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 4d\ ^2F_{3\frac{1}{2}}$ |
| 2266.903 | 10 | 44099.41 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 4d''\ ^2D_{2\frac{1}{2}}$ |
| 2267.038 | 5 | 44096.78 | $4p''\ ^4D^\circ_{3\frac{1}{2}} - 4d''\ ^4D_{2\frac{1}{2}}$ |
| 2267.236 | 100 | 44092.93 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 4d''\ ^2D_{1\frac{1}{2}}$ |
| 2268.732 | 1 | 44063.86 | |
| 2269.008 | 100 | 44058.50 | $4p''\ ^4D_{3\frac{1}{2}} - 4d''\ ^4D^\circ_{3\frac{1}{2}}$ |
| 2269.278 | 2 | 44053.26 | $s^2\ ^2D_{2\frac{1}{2}} - 5p''\ ^4D^\circ_{1\frac{1}{2}}$ |
| 2270.214 | 2000 | 44035.10 | $4s\ ^4F_{3\frac{1}{2}} - 4p\ ^4G^\circ_{4\frac{1}{2}}$ |
| 2270.734 | 100 | 44025.01 | $4p\ ^4F_{3\frac{1}{2}} - 4d\ ^4G_{4\frac{1}{2}}$ |
| 2271.086 | 2 | 44018.19 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 4d\ ^4F_{2\frac{1}{2}}$ |
| 2271.843 | 30 | 44003.52 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 4d\ ^2P_{1\frac{1}{2}}$ |
| 2272.251 | 3 | 43995.62 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 5d\ ^4F_{4\frac{1}{2}}$ |
| 2272.865 | 100 | 43983.74 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d'\ ^2F_{3\frac{1}{2}}$ |
| 2274.058 | 5 | 43960.67 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 4d\ ^4H_{4\frac{1}{2}}$ |
| 2274.595 | 3 | 43950.29 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d'\ ^2F_{2\frac{1}{2}}$ |
| 2274.724 | 200 | 43947.80 | $4s''\ ^4P_{1\frac{1}{2}} - 4p'\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2275.063 | 1 | 43941.25 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 4d'\ ^2D_{1\frac{1}{2}}$ |
| 2275.284 | 1 | 43936.98 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 4d''\ ^4P_{1\frac{1}{2}}$ |
| 2275.684 | 300 | 43929.26 | $4s''\ ^4P_{2\frac{1}{2}} - 4p'\ ^2P^\circ_{1\frac{1}{2}}$ |
| 2276.023 | 150 | 43922.72 | $4p\ ^4F_{3\frac{1}{2}} - 4d\ ^4F_{3\frac{1}{2}}$ |
| 2276.437 | 200 | 43914.73 | $4s''\ ^2P_{1\frac{1}{2}} - 4p''\ ^2P^\circ_{1\frac{1}{2}}$ |
| 2276.672 | 300 | 43910.20 | $4p\ ^4F_{4\frac{1}{2}} - 4d\ ^4D_{3\frac{1}{2}}$ |
| 2277.282 | 800 | 43898.44 | $4s'\ ^2D_{1\frac{1}{2}} - 4p'\ ^2F^\circ_{2\frac{1}{2}}$ |
| 2278.318 | 400 | 43878.48 | $4s'''\ ^2G_{3\frac{1}{2}} - 4p'''\ ^2F^\circ_{2\frac{1}{2}}$ |
| 2278.770 | 800 | 43869.78 | $4s\ ^2F_{3\frac{1}{2}} - 4p\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2279.534 | 1 | 43855.07 | $4p\ ^2G^\circ_{4\frac{1}{2}} - 4d\ ^4F_{4\frac{1}{2}}$ |
| 2279.660 | 15 | 43852.65 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^2P_{1\frac{1}{2}}$ |
| 2280.680 | 3 | 43833.04 | $4p\ ^2G^\circ_{4\frac{1}{2}} - 4d\ ^4G_{5\frac{1}{2}}$ |
| 2280.984 | 75 | 43827.20 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^2F_{2\frac{1}{2}}$ |
| 2281.564 | 30 | 43816.06 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 4d''\ ^2F_{2\frac{1}{2}}$ |
| 2282.361 | 8 | 43800.76 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^2P_{0\frac{1}{2}}$ |
| 2284.995 | 2 | 43750.27 | $5s\ ^4F_{3\frac{1}{2}} - v\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2285.178 | 50 | 43746.77 | $4p'''\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^4P_{2\frac{1}{2}}$ |
| 2285.415 | 5 | 43742.23 | $4p'''\ ^2F^\circ_{2\frac{1}{2}} - 5d\ ^4D_{2\frac{1}{2}}$ |
| 2285.687 | 25 | 43737.03 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 4d\ ^4F_{4\frac{1}{2}}$ |
| 2286.853 | 2 | 43714.73 | |
| 2287.089 | 300 | 43710.22 | $4s\ ^2F_{2\frac{1}{2}} - 4p\ ^2D^\circ_{1\frac{1}{2}}$ |
| 2287.648 | 500 | 43699.54 | $4s''\ ^4P_{2\frac{1}{2}} - 4p'\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2289.209 | 6 | 43669.74 | $4p\ ^2G^\circ_{4\frac{1}{2}} - 4d\ ^4H_{5\frac{1}{2}}$ |
| 2293.626 | 4 | 43585.65 | $4p\ ^4F^\circ_{1\frac{1}{2}} - 4d\ ^4P_{0\frac{1}{2}}$ |
| 2294.628 | 1 | 43566.62 | $5s\ ^4F_{4\frac{1}{2}} - 8p\ ^4G^\circ_{5\frac{1}{2}}$ |
| 2296.089 | 100 | 43538.90 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 4d\ ^2G_{4\frac{1}{2}}$ |
| 2296.552 | 400 | 43530.13 | $4s\ ^2F_{3\frac{1}{2}} - 4p\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2297.141 | 400 | 43518.97 | $4s\ ^4F_{2\frac{1}{2}} - 4p\ ^4D^\circ_{1\frac{1}{2}}$ |
| 2297.489 | 300 | 43512.37 | $4s\ ^4F_{1\frac{1}{2}} - 4p\ ^4D^\circ_{0\frac{1}{2}}$ |
| 2297.735 | 3 | 43507.72 | |
| 2298.270 | 300 | 43497.59 | $4s\ ^2F_{2\frac{1}{2}} - 4p\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2298.417 | 2 | 43494.81 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 4d''\ ^2D_{2\frac{1}{2}}$ |
| 2298.491 | 100 | 43493.41 | $4s''\ ^4P_{1\frac{1}{2}} - 4p'\ ^2P^\circ_{0\frac{1}{2}}$ |
| 2299.058 | 30 | 43482.68 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^2D_{1\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 2299.651 | 200 | 43471.47 | $4s'\ ^2D_{2\frac{1}{2}} - 4p''\ ^4P^\circ_{1\frac{1}{2}}$ |
| 2300.097 | 300 | 43463.04 | $4s'\ ^2D_{2\frac{1}{2}} - 4p''\ ^4P^\circ_{2\frac{1}{2}}$ |
| 2301.014 | 20 | 43445.72 | $4s''\ ^4P_{0\frac{1}{2}} - 4p'\ ^2P^\circ_{0\frac{1}{2}}$ |
| 2302.141 | 1 | 43424.46 | |
| 2302.479 | 200 | 43418.08 | $4s'''\ ^2G_{4\frac{1}{2}} - 4p'''\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2302.996 | 1000 | 43408.34 | $4s\ ^4F_{3\frac{1}{2}} - 4p\ ^4D^\circ_{2\frac{1}{2}}$ |
| 2303.688 | 50 | 43395.30 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 4d\ ^2F_{3\frac{1}{2}}$ |
| 2303.754 | 0 | 43394.05 | $4s'''\ ^2G_{3\frac{1}{2}} - 4p'''\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2303.848 | 50 | 43392.28 | $4s''\ ^2P_{0\frac{1}{2}} - 4p''\ ^2P^\circ_{1\frac{1}{2}}$ |
| 2305.239 | 200 | 43366.10 | $4s''\ ^4P_{1\frac{1}{2}} - 4p'\ ^2D^\circ_{1\frac{1}{2}}$ |
| 2306.028 | 30 | 43351.27 | $s^2\ ^4F_{4\frac{1}{2}} - z\ ^4G^\circ_{5\frac{1}{2}}$ |
| 2307.781 | 50 | 43318.34 | $4s''\ ^4P_{0\frac{1}{2}} - 4p'\ ^2D^\circ_{1\frac{1}{2}}$ |
| 2308.278 | 2 | 43309.01 | |
| 2308.518 | 150 | 43304.51 | $4s''\ ^2P_{1\frac{1}{2}} - 4p''\ ^2D^\circ_{1\frac{1}{2}}$ |
| 2310.147 | 2 | 43273.98 | |
| 2310.610 | 1 | 43265.31 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 4d\ ^4F_{3\frac{1}{2}}$ |
| 2311.061 | 6 | 43256.87 | |
| 2311.341 | 5 | 43251.63 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 4d\ ^4H_{4\frac{1}{2}}$ |
| 2311.585 | 75 | 43247.06 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^2G_{3\frac{1}{2}}$ |
| 2312.054 | 2 | 43238.29 | $s^2\ ^4F_{4\frac{1}{2}} - z\ ^4F^\circ_{4\frac{1}{2}}$ |
| 2312.240 | 50 | 43234.81 | $4s'\ ^2D_{1\frac{1}{2}} - 4p''\ ^4P^\circ_{0\frac{1}{2}}$ |
| 2312.916 | 200 | 43222.18 | $4s'''\ ^2G_{4\frac{1}{2}} - 4p'''\ ^2H^\circ_{5\frac{1}{2}}$ |
| 2313.208 | 3 | 43216.72 | |
| 2313.789 | 2 | 43205.87 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^2F_{2\frac{1}{2}}$ |
| 2315.066 | 2 | 43182.04 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^4F_{1\frac{1}{2}}$ |
| 2315.558 | 20 | 43172.86 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^4G_{5\frac{1}{2}}$ |
| 2315.842 | 2 | 43167.57 | $4p\ ^2G^\circ_{4\frac{1}{2}} - 4d\ ^4D_{3\frac{1}{2}}$ |
| 2316.039 | 1000 | 43163.90 | $4s\ ^4F_{4\frac{1}{2}} - 4p\ ^4D^\circ_{3\frac{1}{2}}$ |
| 2318.321 | 5 | 43121.41 | |
| 2318.509 | 200 | 43117.92 | $4s''\ ^4P_{2\frac{1}{2}} - 4p'\ ^2D^\circ_{1\frac{1}{2}}$ |
| 2319.252 | 15 | 43104.11 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 4d''\ ^4D_{2\frac{1}{2}}$ |
| 2319.750 | 500 | 43094.85 | $4s''\ ^4P_{2\frac{1}{2}} - 4p'\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2321.011 | 30 | 43071.44 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 4d\ ^4G_{4\frac{1}{2}}$ |
| 2321.047 | 15 | 43070.77 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^4D_{1\frac{1}{2}}$ |
| 2321.861 | 15 | 43055.68 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^2F_{3\frac{1}{2}}$ |
| 2322.195 | 10 | 43049.48 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 4d\ ^4D_{3\frac{1}{2}}$ |
| 2323.541 | 30 | 43024.55 | $4p'''\ ^2G^\circ_{3\frac{1}{2}} - 4d'''\ ^2G_{3\frac{1}{2}}$ |
| 2324.094 | 5 | 43014.31 | $4p'''\ ^2G^\circ_{3\frac{1}{2}} - 4d'''\ ^2G_{4\frac{1}{2}}$ |
| 2324.272 | 50 | 43011.02 | |
| 2326.230 | 2 | 42974.82 | |
| 2326.451 | 50 | 42970.74 | $4s\ ^4F_{1\frac{1}{2}} - 4p\ ^4D^\circ_{1\frac{1}{2}}$ |
| 2326.527 | 5 | 42969.33 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^4F_{2\frac{1}{2}}$ |
| 2326.635 | 5 | 42967.34 | $4p'''\ ^2G^\circ_{3\frac{1}{2}} - 4d'''\ ^2H_{4\frac{1}{2}}$ |
| 2329.553 | 20 | 42913.52 | $4p'''\ ^2G^\circ_{4\frac{1}{2}} - 4d'''\ ^2G_{4\frac{1}{2}}$ |
| 2329.937 | 40 | 42906.45 | $4s''\ ^4P_{1\frac{1}{2}} - 4p'\ ^2F^\circ_{2\frac{1}{2}}$ |
| 2330.409 | 30 | 42897.76 | $4p'''\ ^2G^\circ_{4\frac{1}{2}} - 4d'''\ ^2H_{5\frac{1}{2}}$ |
| 2331.121 | 40 | 42884.66 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^2D_{2\frac{1}{2}}$ |
| 2331.760 | 10 | 42872.91 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^4G_{2\frac{1}{2}}$ |
| 2332.108 | 15 | 42866.51 | $4p'''\ ^2G^\circ_{4\frac{1}{2}} - 4d'''\ ^2H_{4\frac{1}{2}}$ |
| 2332.970 | 5 | 42850.67 | |
| 2333.883 | 1 | 42833.91 | $s^2\ ^2D_{2\frac{1}{2}} - 5p''\ ^4P^\circ_{1\frac{1}{2}}$ |
| 2334.584 | 500 | 42821.05 | $4s\ ^2F_{3\frac{1}{2}} - 4p\ ^2G^\circ_{3\frac{1}{2}}$ |
| 2335.100 | 15 | 42811.59 | $s^2\ ^4F_{3\frac{1}{2}} - z\ ^4G^\circ_{4\frac{1}{2}}$ |
| 2336.625 | 30 | 42783.65 | $4s'\ ^2D_{1\frac{1}{2}} - 4p''\ ^4P^\circ_{1\frac{1}{2}}$ |
| 2336.712 | 100 | 42782.06 | $4s''\ ^2P_{0\frac{1}{2}} - 4p''\ ^2D^\circ_{1\frac{1}{2}}$ |
| 2337.268 | 1 | 42771.88 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 4d'\ ^2D_{2\frac{1}{2}}$ |
| 2338.233 | 30 | 42754.23 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^2F_{2\frac{1}{2}}$ |
| 2339.240 | 1 | 42735.83 | |
| 2341.202 | 500 | 42700.02 | $4s''\ ^2P_{1\frac{1}{2}} - 4p''\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2343.381 | 3 | 42660.32 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^4G_{2\frac{1}{2}}$ |
| 2343.491 | 200 | 42658.31 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^2P_{1\frac{1}{2}}$ |
| 2343.947 | 20 | 42650.02 | $4s'''\ ^2G_{4\frac{1}{2}} - 4p'''\ ^2H^\circ_{4\frac{1}{2}}$ |
| 2345.267 | 200 | 42626.01 | $4s'''\ ^2G_{3\frac{1}{2}} - 4p'''\ ^2H^\circ_{4\frac{1}{2}}$ |
| 2345.442 | 50 | 42622.83 | $4s\ ^4F_{2\frac{1}{2}} - 4p\ ^4D^\circ_{2\frac{1}{2}}$ |
| 2349.176 | 50 | 42555.09 | $4p''\ ^2S^\circ_{0\frac{1}{2}} - 4d''\ ^2P_{1\frac{1}{2}}$ |
| 2349.331 | 3 | 42552.28 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^4F_{1\frac{1}{2}}$ |
| 2349.580 | 1 | 42547.77 | $5s\ ^2F_{3\frac{1}{2}} - v\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2349.922 | 30 | 42541.58 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^2F_{2\frac{1}{2}}$ |
| 2349.991 | 60 | 42540.33 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^2P_{0\frac{1}{2}}$ |
| 2350.147 | 3 | 42537.51 | $4p''\ ^4S^\circ_{1\frac{1}{2}} - 4d''\ ^2P_{1\frac{1}{2}}$ |
| 2350.269 | 3 | 42535.30 | $s^2\ ^4F_{2\frac{1}{2}} - z\ ^4G^\circ_{3\frac{1}{2}}$ |
| 2350.845 | 10 | 42524.88 | $4s\ ^2F_{3\frac{1}{2}} - 4p\ ^4F^\circ_{2\frac{1}{2}}$ |
| 2351.204 | 1 | 42518.39 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 4d'\ ^2P_{0\frac{1}{2}}$ |
| 2352.048 | 75 | 42503.13 | $4p''\ ^2S^\circ_{0\frac{1}{2}} - 4d''\ ^2P_{0\frac{1}{2}}$ |
| 2352.226 | 1 | 42499.91 | $s^2\ ^4F_{3\frac{1}{2}} - z\ ^4F^\circ_{3\frac{1}{2}}$ |
| 2353.007 | 10 | 42485.81 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 4d\ ^4P_{2\frac{1}{2}}$ |
| 2353.391 | 2 | 42478.88 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 4d\ ^4D_{2\frac{1}{2}}$ |
| 2353.528 | 1 | 42476.40 | $4p''\ ^4D^\circ_{0\frac{1}{2}} - 4d'\ ^2P_{0\frac{1}{2}}$ |
| 2354.922 | 5 | 42451.26 | $s^2\ ^4F_{1\frac{1}{2}} - z\ ^4G^\circ_{2\frac{1}{2}}$ |
| 2355.147 | 10 | 42447.21 | $4p'''\ ^2G^\circ_{3\frac{1}{2}} - 5d\ ^2G_{3\frac{1}{2}}$ |
| 2356.013 | 75 | 42431.61 | $4p''\ ^4S^\circ_{1\frac{1}{2}} - 4d''\ ^4P_{2\frac{1}{2}}$ |
| 2356.403 | 100 | 42424.58 | $4s\ ^2F_{2\frac{1}{2}} - 4p\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2358.054 | 2 | 42394.88 | $4p''\ ^4D^\circ_{3\frac{1}{2}} - 4d'\ ^2G_{4\frac{1}{2}}$ |
| 2358.208 | 1 | 42392.12 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 4d\ ^4D_{3\frac{1}{2}}$ |
| 2359.816 | 1 | 42363.23 | |
| 2359.862 | 100 | 42362.41 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 4d\ ^4G_{4\frac{1}{2}}$ |
| 2360.396 | 1 | 42352.82 | |
| 2360.766 | 2 | 42346.19 | $4p'''\ ^2G^\circ_{4\frac{1}{2}} - 5d\ ^2G_{3\frac{1}{2}}$ |
| 2362.111 | 5 | 42322.07 | $4p'''\ ^2G^\circ_{3\frac{1}{2}} - 5d\ ^4G_{2\frac{1}{2}}$ |
| 2362.351 | 1 | 42317.78 | $4p'''\ ^2G^\circ_{3\frac{1}{2}} - 5d\ ^2H_{4\frac{1}{2}}$ |
| 2362.527 | 1 | 42314.62 | |
| 2363.649 | 1 | 42294.54 | $s^2\ ^4F_{2\frac{1}{2}} - z\ ^4F^\circ_{2\frac{1}{2}}$ |
| 2364.305 | 50 | 42282.81 | $s^2\ ^2H_{5\frac{1}{2}} - z\ ^2I^\circ_{6\frac{1}{2}}$ |
| 2365.383 | 2 | 42263.54 | $4p'''\ ^2G^\circ_{3\frac{1}{2}} - 4d'''\ ^2F_{3\frac{1}{2}}$ |
| 2365.576 | 100 | 42260.09 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 4d\ ^4F_{3\frac{1}{2}}$ |
| 2365.739 | 15 | 42257.18 | $4p'''\ ^2G^\circ_{3\frac{1}{2}} - 4d'''\ ^2F_{2\frac{1}{2}}$ |
| 2366.542 | 100 | 42242.84 | $4s''\ ^4P_{1\frac{1}{2}} - 4p''\ ^4P^\circ_{0\frac{1}{2}}$ |
| 2367.385 | 100 | 42227.80 | $4s\ ^4F_{3\frac{1}{2}} - 4p\ ^4D^\circ_{3\frac{1}{2}}$ |
| 2367.668 | 2 | 42222.75 | |
| 2368.935 | 2 | 42200.17 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 4d'\ ^2D_{1\frac{1}{2}}$ |
| 2369.218 | 50 | 42195.13 | $4s''\ ^4P_{0\frac{1}{2}} - 4p''\ ^4P^\circ_{0\frac{1}{2}}$ |
| 2369.512 | 2 | 42189.90 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 4d\ ^4P_{2\frac{1}{2}}$ |
| 2369.863 | 15 | 42183.65 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 5s''\ ^4P_{0\frac{1}{2}}$ |
| 2370.765 | 50 | 42167.60 | $4p''\ ^4S^\circ_{1\frac{1}{2}} - 4d''\ ^2D_{1\frac{1}{2}}$ |
| 2371.038 | 40 | 42162.74 | $4p'''\ ^2G^\circ_{4\frac{1}{2}} - 4d'''\ ^2F_{3\frac{1}{2}}$ |
| 2372.361 | 15 | 42139.23 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^4D_{2\frac{1}{2}}$ |
| 2374.582 | 20 | 42099.82 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^4G_3$ |
| 2374.802 | 5 | 42095.92 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 4d\ ^4D_{3\frac{1}{2}}$ |
| 2375.418 | 1000 | 42085.01 | $4s\ ^2F_{2\frac{1}{2}} - 4p\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2375.901 | 3 | 42076.45 | $s^2\ ^2H_{5\frac{1}{2}} - 4f\ ^4\ I^\circ_{6\frac{1}{2}}$ |
| 2376.010 | 75 | 42074.52 | $4s\ ^4F_{1\frac{1}{2}} - 4p\ ^4D^\circ_{2\frac{1}{2}}$ |
| 2377.350 | 5 | 42050.81 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 4d'\ ^2F_{2\frac{1}{2}}$ |
| 2378.580 | 10 | 42029.07 | $4p''\ ^2S^\circ_{0\frac{1}{2}} - 4d''\ ^4P_{1\frac{1}{2}}$ |
| 2379.574 | 100 | 42011.51 | $4p''\ ^4S^\circ_{1\frac{1}{2}} - 4d''\ ^4P_{1\frac{1}{2}}$ |
| 2380.353 | 10 | 41997.76 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^4D_{1\frac{1}{2}}$ |
| 2380.723 | 5 | 41991.24 | $s^2\ ^2F_{3\frac{1}{2}} - w\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2381.098 | 1 | 41984.62 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^4D_{0\frac{1}{2}}$ |
| 2381.210 | 30 | 41982.65 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^2F_{3\frac{1}{2}}$ |
| 2381.516 | 10 | 41977.26 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 5s''\ ^4P_{1\frac{1}{2}}$ |
| 2381.892 | 8 | 41970.63 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 5s\ ^2F_{3\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 2381.993 | 8 | 41968.85 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 5s''\ ^4P_{1\frac{1}{2}}$ |
| 2382.439 | 40 | 41960.99 | $4p''\ ^4S^\circ_{1\frac{1}{2}} - 4d''\ ^4P_{0\frac{1}{2}}$ |
| 2382.675 | 8 | 41956.84 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d''\ ^4D_{1\frac{1}{2}}$ |
| 2383.540 | 5 | 41941.61 | $4p''\ ^4D^\circ_{3\frac{1}{2}} - 4d'\ ^2F_{3\frac{1}{2}}$ |
| 2384.745 | 100 | 41920.42 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^4F_{3\frac{1}{2}}$ |
| 2386.115 | 15 | 41896.35 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^4F_{2\frac{1}{2}}$ |
| 2386.438 | 5 | 41890.69 | $4p''\ ^4S^\circ_{1\frac{1}{2}} - 4d''\ ^2F_{2\frac{1}{2}}$ |
| 2387.764 | 100 | 41867.42 | $4s\ ^2F_{3\frac{1}{2}} - 4p\ ^4F^\circ_{3\frac{1}{2}}$ |
| 2391.805 | 20 | 41796.69 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 5s''\ ^4P_{2\frac{1}{2}}$ |
| 2392.106 | 30 | 41791.43 | $4s''\ ^4P_{1\frac{1}{2}} - 4p''\ ^4P^\circ_{1\frac{1}{2}}$ |
| 2392.289 | 5 | 41788.24 | $4p''\ ^4P^\circ_{1\frac{1}{2}} - 5s''\ ^4P_{2\frac{1}{2}}$ |
| 2392.588 | 100 | 41783.02 | $4s''\ ^4P_{1\frac{1}{2}} - 4p''\ ^4P^\circ_{2\frac{1}{2}}$ |
| 2394.519 | 1000 | 41749.32 | $4s\ ^2F_{3\frac{1}{2}} - 4p\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2394.843 | 100 | 41743.68 | $4s''\ ^4P_{0\frac{1}{2}} - 4p''\ ^4P^\circ_{1\frac{1}{2}}$ |
| 2395.507 | 1 | 41732.11 | $4p''\ ^4P^\circ_{0\frac{1}{2}} - 5s''\ ^4P_{0\frac{1}{2}}$ |
| 2397.509 | 1 | 41697.26 | |
| 2398.288 | 75 | 41683.72 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^4F_{2\frac{1}{2}}$ |
| 2398.625 | 2 | 41677.86 | $4s''\ ^2P_{1\frac{1}{2}} - 4p''\ ^4D^\circ_{0\frac{1}{2}}$ |
| 2400.374 | 1 | 41647.50 | $5s\ ^4F_{3\frac{1}{2}} - s\ ^4D^\circ_{2\frac{1}{2}}$ |
| 2400.925 | 3 | 41637.94 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 4d'\ ^2P_{1\frac{1}{2}}$ |
| 2401.929 | 100 | 41620.54 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^4P_{1\frac{1}{2}}$ |
| 2403.708 | 1 | 41589.73 | |
| 2403.956 | 30 | 41585.44 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^2P_{1\frac{1}{2}}$ |
| 2404.548 | 1 | 41575.21 | $4p'\ ^2F^\circ_{2\frac{1}{2}} - 5s''\ ^2P_{1\frac{1}{2}}$ |
| 2404.881 | 10 | 41569.45 | $4p''\ ^4S^\circ_{1\frac{1}{2}} - 4d''\ ^2D_{2\frac{1}{2}}$ |
| 2405.163 | 100 | 41564.58 | $4s''\ ^2P_{0\frac{1}{2}} - 4p''\ ^4D^\circ_{2\frac{1}{2}}$ |
| 2406.389 | 15 | 41543.40 | $4s''\ ^4P_{2\frac{1}{2}} - 4p''\ ^4P^\circ_{1\frac{1}{2}}$ |
| 2406.875 | 50 | 41535.01 | $4s''\ ^4P_{2\frac{1}{2}} - 4p''\ ^4P^\circ_{2\frac{1}{2}}$ |
| 2407.890 | 40 | 41517.51 | $4p''\ ^4P^\circ_{0\frac{1}{2}} - 5s''\ ^4P_{1\frac{1}{2}}$ |
| 2408.111 | 3 | 41513.70 | $4p'''\ ^2G^\circ_{4\frac{1}{2}} - 4d'''\ ^2\ I_{5\frac{1}{2}}$ |
| 2409.209 | 2 | 41494.78 | $4p'''\ ^2G^\circ_{3\frac{1}{2}} - 5d\ ^4G_{3\frac{1}{2}}$ |
| 2410.027 | 5 | 41480.70 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 4d\ ^4P_{2\frac{1}{2}}$ |
| 2410.744 | 10 | 41468.36 | $4s\ ^2F_{3\frac{1}{2}} - 4p\ ^4G^\circ_{2\frac{1}{2}}$ |
| 2412.265 | 10 | 41442.21 | $4s\ ^4F_{2\frac{1}{2}} - 4p\ ^4D^\circ_{3\frac{1}{2}}$ |
| 2413.040 | 50 | 41428.91 | $4s\ ^2F_{2\frac{1}{2}} - 4p\ ^4F^\circ_{1\frac{1}{2}}$ |
| 2414.329 | 10 | 41406.79 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 4d'\ ^2G_{3\frac{1}{2}}$ |
| 2415.067 | 5 | 41394.14 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 5s''\ ^2P_{0\frac{1}{2}}$ |
| 2415.502 | 15 | 41386.68 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 4d\ ^4D_{3\frac{1}{2}}$ |
| 2416.134 | 2000 | 41375.86 | $4s\ ^2F_{2\frac{1}{2}} - 4p\ ^2G^\circ_{3\frac{1}{2}}$ |
| 2416.306 | 30 | 41372.91 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^2P_{1\frac{1}{2}}$ |
| 2418.889 | 1 | 41328.74 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 5s\ ^4F_{1\frac{1}{2}}$ |
| 2420.317 | 40 | 41304.35 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^4P_{0\frac{1}{2}}$ |
| 2424.623 | 2 | 41231.01 | $5s\ ^4F_{4\frac{1}{2}} - 4f'\ ^2H^\circ_{4\frac{1}{2}}$ |
| 2426.316 | 3 | 41202.24 | $5s\ ^4F_{3\frac{1}{2}} - v\ ^4F^\circ_{3\frac{1}{2}}$ |
| 2431.561 | 40 | 41113.37 | $4s''\ ^2P_{0\frac{1}{2}} - 4p''\ ^4D^\circ_{1\frac{1}{2}}$ |
| 2432.670 | 20 | 41094.63 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 5s\ ^2F_{2\frac{1}{2}}$ |
| 2433.556 | 100 | 41079.67 | $4s\ ^2F_{2\frac{1}{2}} - 4p\ ^4F^\circ_{2\frac{1}{2}}$ |
| 2434.319 | 2 | 41066.79 | $4p''\ ^2P^\circ_{0\frac{1}{2}} - 4d'''\ ^4D_{0\frac{1}{2}}$ |
| 2435.491 | 8 | 41047.03 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^4D_{3\frac{1}{2}}$ |
| 2435.958 | 8 | 41039.16 | $4p''\ ^2P^\circ_{0\frac{1}{2}} - 4d''\ ^4D_{1\frac{1}{2}}$ |
| 2436.313 | 5 | 41033.18 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 4d'\ ^2P_{1\frac{1}{2}}$ |
| 2437.892 | 500 | 41006.61 | $4s\ ^2F_{3\frac{1}{2}} - 4p\ ^4F^\circ_{4\frac{1}{2}}$ |
| 2438.997 | 2 | 40988.03 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 5s''\ ^2P_{1\frac{1}{2}}$ |
| 2441.330 | 10 | 40948.87 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 4d'\ ^2F_{3\frac{1}{2}}$ |
| 2447.013 | 10 | 40853.77 | $4p'\ ^2F^\circ_{2\frac{1}{2}} - 5s''\ ^4P_{1\frac{1}{2}}$? |
| 2447.257 | 3 | 40849.70 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 4d'\ ^2P_{0\frac{1}{2}}$ |
| 2447.393 | 30 | 40847.43 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^4F_{3\frac{1}{2}}$ |
| 2447.590 | 5 | 40844.14 | $5s\ ^4F_{3\frac{1}{2}} - w\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2448.080 | 1 | 40835.97 | $s^2\ ^2F_{2\frac{1}{2}} - v\ ^4F^\circ_{2\frac{1}{2}}$ |
| 2449.234 | 5 | 40816.73 | $s^2\ ^2F_{2\frac{1}{2}} - v\ ^4F^\circ_{1\frac{1}{2}}$ |
| 2449.347 | 15 | 40814.85 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 4d''\ ^4P_{2\frac{1}{2}}$ |
| 2450.839 | 100 | 40790.00 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 5s\ ^2F_{3\frac{1}{2}}$ |
| 2452.160 | 8 | 40768.03 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 5s\ ^4F_{3\frac{1}{2}}$ |
| 2452.476 | 2 | 40762.78 | |
| 2455.519 | 30 | 40712.26 | $4s\ ^2F_{3\frac{1}{2}} - 4p\ ^4G^\circ_{3\frac{1}{2}}$ |
| 2455.651 | 5 | 40710.08 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 5s''\ ^2P_{0\frac{1}{2}}$ |
| 2457.723 | 3 | 40675.76 | |
| 2457.865 | 30 | 40673.41 | $4p'\ ^2F^\circ_{2\frac{1}{2}} - 5s''\ ^4P_{2\frac{1}{2}}$ |
| 2459.180 | 20 | 40651.66 | $4p\ ^4D^\circ_{2\frac{1}{2}} - 6s\ ^4F_{2\frac{1}{2}}$ |
| 2460.038 | 50 | 40637.48 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d'\ ^2S_{0\frac{1}{2}}$ |
| 2461.763 | 10 | 40609.01 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 5s''\ ^4P_{0\frac{1}{2}}$ |
| 2465.493 | 15 | 40547.58 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^4P_{1\frac{1}{2}}$ |
| 2465.940 | 3 | 40540.23 | $s^2\ ^2D_{2\frac{1}{2}} - 5p'\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2466.470 | 8 | 40531.52 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 4d'\ ^2D_{1\frac{1}{2}}$ |
| 2467.380 | 5 | 40516.57 | |
| 2467.647 | 20 | 40512.19 | $s^2\ ^2H_{4\frac{1}{2}} - z\ ^2\ I^\circ_{5\frac{1}{2}}$ |
| 2468.711 | 1 | 40494.73 | |
| 2468.848 | 2 | 40492.48 | $5s\ ^4F_{3\frac{1}{2}} - 4f'\ ^2G^\circ_{4\frac{1}{2}}$? |
| 2469.520 | 3 | 40481.46 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 5s''\ ^4P_{0\frac{1}{2}}$? |
| 2470.026 | 1 | 40473.17 | $s^2\ ^2F_{2\frac{1}{2}} - 4f'\ ^2G^\circ_{3\frac{1}{2}}$ |
| 2470.429 | 2 | 40466.57 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 5s\ ^2F_{2\frac{1}{2}}$ |
| 2470.503 | 1 | 40465.35 | |
| 2472.282 | 10 | 40436.24 | $4p'''\ ^2F^\circ_{2\frac{1}{2}} - 4d''\ ^2P_{1\frac{1}{2}}$ |
| 2472.507 | 15 | 40432.56 | $4p\ ^4D^\circ_{1\frac{1}{2}} - 5s\ ^4F_{1\frac{1}{2}}$ |
| 2473.085 | 50 | 40423.11 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d'\ ^2P_{1\frac{1}{2}}$ |
| 2473.148 | 100 | 40422.08 | $4s\ ^2F_{2\frac{1}{2}} - 4p\ ^4F^\circ_{3\frac{1}{2}}$ |
| 2473.444 | 2 | 40417.24 | $s^2\ ^2F_{3\frac{1}{2}} - v\ ^4F^\circ_{2\frac{1}{2}}$ |
| 2474.850 | 10 | 40394.28 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 5s''\ ^4P_{1\frac{1}{2}}$ |
| 2475.147 | 1 | 40389.44 | |
| 2475.858 | 2 | 40377.84 | $s^2\ ^2F_{3\frac{1}{2}} - w\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2477.193 | 1 | 40356.08 | $s^2\ ^2F_{2\frac{1}{2}} - 4f'\ ^2F^\circ_{2\frac{1}{2}}$ |
| 2478.497 | 10 | 40334.85 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^4P_{1\frac{1}{2}}$ |
| 2479.972 | 1 | 40310.86 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 4d'\ ^2F_{2\frac{1}{2}}$ |
| 2482.254 | 20 | 40273.81 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 4d''\ ^2F_{2\frac{1}{2}}$ |
| 2482.680 | 15 | 40266.90 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 5s''\ ^4P_{1\frac{1}{2}}$ |
| 2484.204 | 200 | 40242.19 | $4p\ ^4D^\circ_{3\frac{1}{2}} - 5s\ ^4F_{4\frac{1}{2}}$ |
| 2484.381 | 10 | 40239.33 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d'\ ^2P_{0\frac{1}{2}}$ |
| 2484.526 | 2 | 40236.98 | $4p'\ ^2F^\circ_{3\frac{1}{2}} - 5s''\ ^4P_{2\frac{1}{2}}$ |
| 2485.960 | 30 | 40213.77 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 5s''\ ^4P_{2\frac{1}{2}}$ |
| 2489.081 | 1 | 40163.35 | $4p\ ^4G^\circ_{4\frac{1}{2}} - 5s\ ^2F_{3\frac{1}{2}}$ |
| 2491.695 | 1 | 40121.22 | $4p'''\ ^2G^\circ_{4\frac{1}{2}} - 5d\ ^4G_{4\frac{1}{2}}$? |
| 2493.666 | 1 | 40089.51 | |
| 2495.900 | 50 | 40053.63 | $4p\ ^4D^\circ_{2\frac{1}{2}} - s^2\ ^2F_{3\frac{1}{2}}$ |
| 2496.807 | 1 | 40039.08 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 4d'''\ ^4F_{2\frac{1}{2}}$ |
| 2497.621 | 1 | 40026.03 | $s^2\ ^2F_{3\frac{1}{2}} - 4f'\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2497.805 | 10 | 40023.08 | $4s\ ^2F_{2\frac{1}{2}} - 4p\ ^4G^\circ_{2\frac{1}{2}}$ |
| 2500.873 | 2 | 39973.99 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^4D_{3\frac{1}{2}}$ |
| 2501.105 | 1 | 39970.28 | |
| 2502.215 | 5 | 39952.55 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 4d''\ ^2D_{2\frac{1}{2}}$ |
| 2503.256 | 100 | 39935.94 | $4p'''\ ^2H^\circ_{4\frac{1}{2}} - 5s'''\ ^2G_{3\frac{1}{2}}$ |
| 2503.509 | 5 | 39931.90 | $4p'''\ ^2H^\circ_{4\frac{1}{2}} - 5s'''\ ^2G_{4\frac{1}{2}}$ |
| 2504.175 | 1 | 39921.28 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d'\ ^2D_{1\frac{1}{2}}$ |
| 2504.424 | 5 | 39917.31 | $5s\ ^2F_{3\frac{1}{2}} - w\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2505.843 | 150 | 39894.71 | $4s''\ ^4P_{1\frac{1}{2}} - 4p'\ ^2P^\circ_{1\frac{1}{2}}$ |
| 2506.091 | 100 | 39890.76 | $4p\ ^4D^\circ_{0\frac{1}{2}} - 5s\ ^4F_{1\frac{1}{2}}$ |
| 2510.450 | 8 | 39821.50 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 4d''\ ^4F_{4\frac{1}{2}}$ |
| 2510.871 | 500 | 39814.83 | $4s\ ^2F_{3\frac{1}{2}} - 4p\ ^4G^\circ_{4\frac{1}{2}}$ |
| 2511.016 | 5 | 39812.53 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 5s''\ ^4P_{1\frac{1}{2}}$ |
| 2511.235 | 10h | 39809.06 | |
| 2511.965 | 2 | 39797.49 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 5s''\ ^4P_{0\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition | λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|---|---|---|---|
| 2514.627 | 200 | 39755.36 | $4p\ ^4D^\circ_{11/2} - 5s\ ^4F_{21/2}$ | 2583.998 | 200 | 38688.14 | $4s''\ ^2P_{01/2} - 4p'\ ^2P^\circ_{01/2}$ |
| 2515.371 | 5 | 39743.60 | $4p'''\ ^2F^\circ_{21/2} - 4d''\ ^2F_{31/2}$ | 2584.314 | 50 | 38683.41 | $4p'''\ ^2F^\circ_{21/2} - 5s'''\ ^2G_{31/2}$ |
| 2516.875 | 15 | 39719.85 | $4p''\ ^2P^\circ_{01/2} - 4d'\ ^2S_{01/2}$ | 2586.106 | 1 | 38656.61 | |
| 2517.469 | 20 | 39710.48 | $4p\ ^4G^\circ_{21/2} - 5s\ ^2F_{21/2}$ | 2586.285 | 2 | 38653.93 | $4p\ ^4F^\circ_{21/2} - 5s\ ^2F_{21/2}$ |
| 2520.351 | 5 | 39665.08 | $4s''\ ^2P_{11/2} - 4p'\ ^2D^\circ_{21/2}$ | 2586.798 | 10 | 38646.27 | |
| 2521.217 | 5 | 39651.45 | $5s\ ^2F_{21/2} - u\ ^2G^\circ_{31/2}$ | 2587.289 | 8 | 38638.93 | $4s\ ^2F_{21/2} - 4p\ ^4D^\circ_{11/2}$ |
| 2521.853 | 10 | 39641.46 | $5s\ ^2F_{31/2} - u\ ^2F^\circ_{31/2}$ | 2587.598 | 10 | 38634.32 | $4p''\ ^4D^\circ_{21/2} - 5s''\ ^2P_{11/2}$ |
| 2522.266 | 1h | 39634.97 | $4p\ ^4D^\circ_{21/2} - s^2\ ^2F_{21/2}$ | 2588.310 | 20 | 38623.69 | $4s''\ ^2P_{11/2} - 4p'\ ^2F^\circ_{21/2}$ |
| 2522.453 | 75 | 39632.03 | $4p'\ ^2D^\circ_{21/2} - 5s''\ ^4P_{21/2}$ | 2589.584 | 18 | 38604.69 | |
| 2524.213 | 20 | 39604.40 | | 2590.787 | 2 | 38586.77 | |
| 2525.296 | 300 | 39587.41 | $4p\ ^4D^\circ_{21/2} - 5s\ ^4F_{31/2}$ | 2591.193 | 1 | 38580.72 | |
| 2526.670 | 3 | 39565.89 | | 2591.259 | 15 | 38579.74 | $4d\ ^2H_{51/2} - 7f\ ^2\ I^\circ_{61/2}$ ÷ |
| 2527.471 | 15 | 39553.35 | $4p''\ ^4P^\circ_{11/2} - 5s'\ ^2D_{11/2}$ | 2592.155 | 0 | 38566.41 | $4d\ ^4H_{51/2} - 7f\ ^4G^\circ_{51/2}$ |
| 2530.532 | 5 | 39505.51 | $4p''\ ^2P^\circ_{01/2} - 5d'\ ^2P_{11/2}$ | 2592.390 | 1 | 38562.91 | $4p''\ ^4D^\circ_{11/2} - 5s''\ ^2P_{11/2}$ |
| 2532.231 | 5 | 39479.00 | $5s\ ^2F_{21/2} - u\ ^2F^\circ_{21/2}$ | 2592.477 | 15 | 38561.62 | $4d\ ^4H_{51/2} - 7f\ ^4F^\circ_{41/2}$ |
| 2534.959 | 150 | 39436.52 | $4p''\ ^4P^\circ_{21/2} - 5s'\ ^2D_{21/2}$ | 2592.530 | 1 | 38560.83 | $4s''\ ^2P_{01/2} - 4p'\ ^2D^\circ_{11/2}$ |
| 2535.302 | 2 | 39431.18 | $z\ ^4F^\circ_{41/2} - 8s\ ^4F_{41/2}$ | 2592.595 | 5 | 38559.86 | $4d\ ^4H_{51/2} - 7f\ ^4H^\circ_{61/2}$ |
| 2535.501 | 100 | 39428.09 | $4p''\ ^4P^\circ_{11/2} - 5s'\ ^2D_{21/2}$ | 2593.913 | 3 | 38540.27 | $4p'''\ ^2F^\circ_{21/2} - 4d''\ ^4D_{11/2}$ |
| 2535.580 | 5 | 39426.86 | $4p\ ^4G^\circ_{41/2} - s^2\ ^2F_{31/2}$ | 2594.645 | 75 | 38529.40 | $4p\ ^4G^\circ_{31/2} - s^2\ ^2F_{31/2}$ |
| 2535.696 | 3 | 39425.06 | $4p'''\ ^2F^\circ_{21/2} - 4d''\ ^4F_{31/2}$ | 2595.973 | 10 | 38509.69 | $4p\ ^4G^\circ_{21/2} - 5s\ ^2F_{31/2}$ |
| 2537.157 | 15 | 39402.36 | $4p'\ ^2P^\circ_{11/2} - 5s''\ ^4P_{21/2}$ | 2596.284 | 2 | 38505.08 | |
| 2539.100 | 75 | 39372.21 | $4s''\ ^2P_{01/2} - 4p'\ ^2P^\circ_{11/2}$ | 2596.448 | 1 | 38502.64 | |
| 2539.902 | 100 | 39359.78 | $4p'''\ ^2H^\circ_{51/2} - 5s'''\ ^2G_{41/2}$ | 2596.569 | 5 | 38500.85 | |
| 2541.876 | 2 | 39329.21 | | 2596.685 | 5 | 38499.13 | |
| 2541.994 | 3 | 39327.38 | | 2597.575 | 3 | 38485.94 | $4d\ ^4P_{11/2} - 7f\ ^4D^\circ_{21/2}$ |
| 2542.354 | 15d | 39321.82 | $4p''\ ^2P^\circ_{01/2} - 4d'\ ^2P_{01/2}$ | 2599.936 | 10 | 38450.99 | |
| 2545.903 | 200 | 39267.01 | $4s\ ^2F_{21/2} - 4p\ ^4G^\circ_{31/2}$ | 2600.022 | 10 | 38449.72 | |
| 2545.990 | 50 | 39265.66 | $4p\ ^4G^\circ_{31/2} - 5s\ ^2F_{31/2}$ | 2600.779 | 300 | 38438.53 | $4p'\ ^2F^\circ_{21/2} - 5s'\ ^2D_{11/2}$ |
| 2547.188 | 8 | 39247.20 | $4s'''\ ^2G_{31/2} - 4p''\ ^2D^\circ_{21/2}$ | 2601.029 | 200 | 38434.84 | $4p\ ^4G^\circ_{41/2} - 5s\ ^4F_{41/2}$ |
| 2549.548 | 75 | 39210.87 | $4s''\ ^2P_{11/2} - 4p'\ ^2P^\circ_{01/2}$? | 2601.835 | 2 | 38422.93 | |
| 2551.034 | 10 | 39188.03 | $4s\ ^2F_{31/2} - 4p\ ^4D^\circ_{21/2}$ | 2602.113 | 3 | 38418.83 | |
| 2552.617 | 100 | 39163.73 | $4p'''\ ^2F^\circ_{31/2} - 5s'''\ ^2G_{41/2}$ | 2602.374 | 30 | 38414.97 | $s^2\ ^4F_{41/2} - z\ ^6G^\circ_{51/2}$ |
| 2554.988 | 200 | 39127.39 | $4p\ ^4G^\circ_{31/2} - 5s\ ^4F_{21/2}$ | 2603.180 | 8 | 38403.08 | $s^2\ ^4P_{21/2} - 5p\ ^4G^\circ_{21/2}$ |
| 2556.265 | 3 | 39107.84 | $4p''\ ^4S^\circ_{11/2} - 4d'\ ^2P_{11/2}$ | | | | $4d\ ^4G_{51/2} - 7f\ ^4G^\circ_{51/2}$ |
| 2556.356 | 2 | 39106.45 | $4p''\ ^4S^\circ_{11/2} - 4d'\ ^2D_{21/2}$ | 2603.492 | 0 | 38398.48 | $4d\ ^4G_{51/2} - 7f\ ^4F^\circ_{41/2}$ |
| 2556.638 | 15 | 39102.14 | $4p''\ ^4P^\circ_{01/2} - 5s'\ ^2D_{11/2}$ | 2603.620 | 15 | 38396.59 | $4d\ ^4G_{51/2} - 7f\ ^4H^\circ_{61/2}$ |
| 2557.868 | 15 | 39083.34 | $4s''\ ^2P_{11/2} - 4p'\ ^2D^\circ_{11/2}$ | 2604.671 | 10 | 38381.10 | $4d\ ^4F_{41/2} - 7f\ ^4G^\circ_{51/2}$ |
| 2558.830 | 0 | 39068.64 | $4d\ ^4D_{31/2} - 7f\ ^4F^\circ_{31/2}$ | | | | $4d\ ^4F_{41/2} - 7f\ ^4F^\circ_{31/2}$ |
| 2559.135 | 8 | 39063.99 | $4d\ ^4D_{31/2} - 7f\ ^4F^\circ_{41/2}$ | 2604.998 | 10 | 38376.28 | $4d\ ^4F_{41/2} - 7f\ ^4F^\circ_{41/2}$ |
| 2559.922 | 5 | 39051.98 | $4d\ ^4D_{31/2} - 7f\ ^4P^\circ_{21/2}$ | 2605.331 | 300 | 38371.37 | $4p\ ^4G^\circ_{21/2} - 5s\ ^4F_{21/2}$ |
| 2560.156 | 150 | 39048.41 | $4p\ ^4G^\circ_{21/2} - 5s\ ^4F_{11/2}$ | 2605.516 | 3 | 38368.65 | $4d\ ^4F_{41/2} - 7f\ ^4D^\circ_{31/2}$? |
| 2562.356 | 5 | 39014.89 | | 2606.255 | 500 | 38357.77 | $4p\ ^2G^\circ_{31/2} - 5s\ ^2F_{21/2}$ |
| 2565.210 | 15 | 38971.48 | $4p\ ^4F^\circ_{41/2} - 5s\ ^2F_{31/2}$ | 2609.286 | 15 | 38313.22 | $4p'\ ^2F^\circ_{21/2} - 5s'\ ^2D_{21/2}$ |
| 2565.923 | 500 | 38960.65 | $4p\ ^4G^\circ_{41/2} - 5s\ ^4F_{31/2}$ | 2609.945 | 500 | 38303.54 | $4p\ ^4G^\circ_{51/2} - 5s\ ^4F_{41/2}$ |
| 2566.097 | 5 | 38958.01 | $4d\ ^4P_{21/2} - 7f\ ^4P^\circ_{21/2}$ | 2610.170 | 5 | 38300.24 | |
| 2566.241 | 5 | 38955.83 | | 2610.478 | 3 | 38295.72 | |
| 2566.856 | 1 | 38946.49 | | 2611.647 | 75 | 38278.58 | $4s'''\ ^2G_{41/2} - 4p''\ ^4D^\circ_{31/2}$ |
| 2567.120 | 3 | 38942.49 | | 2611.965 | 2 | 38273.92 | |
| 2568.136 | 3 | 38927.08 | $4p''\ ^4D^\circ_{01/2} - 5s''\ ^2P_{01/2}$ | 2612.235 | 8 | 38269.97 | |
| 2568.670 | 3 | 38918.99 | $4p'''\ ^2F^\circ_{31/2} - 4d''\ ^4D_{31/2}$ | 2613.291 | 2 | 38254.50 | $4s'''\ ^2G_{31/2} - 4p''\ ^4D^\circ_{31/2}$ |
| 2568.793 | 1 | 38917.13 | $s^2\ ^2D_{11/2} - 5p'\ ^2D^\circ_{21/2}$ | 2614.633 | 3 | 38234.87 | $4p\ ^4F^\circ_{41/2} - s^2\ ^2F_{31/2}$ |
| 2572.207 | 2 | 38865.48 | | 2615.056 | 500 | 38228.69 | $4p\ ^2G^\circ_{41/2} - 5s\ ^2F_{31/2}$ |
| 2572.495 | 3 | 38861.13 | $5s\ ^4F_{41/2} - 7p\ ^4G^\circ_{51/2}$ | 2617.336 | 10 | 38195.39 | $4d\ ^4F_{31/2} - 7f\ ^4F^\circ_{31/2}$ |
| 2575.004 | 10 | 38823.26 | | 2617.543 | 5 | 38192.37 | |
| 2576.247 | 2 | 38804.53 | | 2617.967 | 2 | 38186.18 | $4d\ ^4F_{31/2} - 7f\ ^4D^\circ_{21/2}$ |
| 2578.805 | 1 | 38766.04 | | 2623.071 | 10 | 38111.88 | $4s'''\ ^2G_{31/2} - 4p''\ ^4D^\circ_{21/2}$ |
| 2580.622 | 5 | 38738.75 | $4p\ ^4D^\circ_{11/2} - s^2\ ^2F_{21/2}$ | 2623.154 | 20 | 38110.68 | $4p\ ^4F^\circ_{31/2} - 5s\ ^2F_{31/2}$ |
| 2582.326 | 0 | 38713.19 | $4d\ ^4H_{61/2} - 7f\ ^4G^\circ_{51/2}$ | 2624.367 | 10 | 38093.06 | $4d\ ^4G_{41/2} - 7f\ ^4F^\circ_{31/2}$ |
| 2582.751 | 10 | 38706.82 | $4d\ ^4H_{61/2} - 7f\ ^4H^\circ_{61/2}$ | 2624.697 | 15 | 38088.27 | $4d\ ^4G_{41/2} - 7f\ ^4F^\circ_{41/2}$ |
| 2583.401 | 20 | 38697.08 | $4d\ ^4H_{61/2} - 7f\ ^4\ I^\circ_{71/2}$ | 2626.426 | 200 | 38063.20 | $4p\ ^4G^\circ_{31/2} - 5s\ ^4F_{31/2}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 2626.570 | 5 | 38061.11 | |
| 2626.888 | 40 | 38056.51 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 5s''\ ^4P_{0\frac{1}{2}}$ |
| 2629.787 | 40 | 38014.56 | $4p''\ ^4D^\circ_{0\frac{1}{2}} - 5s''\ ^4P_{0\frac{1}{2}}$ |
| 2630.273 | 30 | 38007.53 | $4s\ ^2F_{3\frac{1}{2}} - 4p\ ^4D^\circ_{3\frac{1}{2}}$ |
| 2630.545 | 1 | 38003.60 | $4d\ ^4D_{2\frac{1}{2}} - 8p\ ^4G^\circ_{3\frac{1}{2}}$ |
| 2631.349 | 100 | 37991.99 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 5s\ ^4F_{1\frac{1}{2}}$ |
| 2632.040 | 5 | 37982.02 | $5s\ ^4F_{4\frac{1}{2}} - t\ ^4D^\circ_{3\frac{1}{2}}$ |
| 2632.255 | 50 | 37978.92 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 5s'\ ^2D_{1\frac{1}{2}}$ |
| 2632.713 | 150 | 37972.31 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 5s\ ^4F_{2\frac{1}{2}}$ |
| 2633.054 | 3 | 37967.39 | $4d\ ^4D_{2\frac{1}{2}} - 7f\ ^4D^\circ_{2\frac{1}{2}}$ |
| 2633.558 | 2 | 37960.13 | $4s''\ ^2P_{1\frac{1}{2}} - 4p''\ ^4P^\circ_{0\frac{1}{2}}$ |
| 2636.824 | 75 | 37913.11 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 5s''\ ^4P_{1\frac{1}{2}}$ |
| 2638.336 | 2 | 37891.39 | |
| 2639.358 | 200 | 37876.72 | $4p'\ ^2F^\circ_{3\frac{1}{2}} - 5s'\ ^2D_{2\frac{1}{2}}$ |
| 2640.970 | 10 | 37853.60 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 5s'\ ^2D_{2\frac{1}{2}}$ |
| 2641.117 | 40 | 37851.49 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 5s'\ ^2D_{1\frac{1}{2}}$ |
| 2641.790 | 50 | 37841.85 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 5s''\ ^4P_{1\frac{1}{2}}$ |
| 2644.726 | 10 | 37799.84 | $4p''\ ^4D^\circ_{0\frac{1}{2}} - 5s''\ ^4P_{1\frac{1}{2}}$ |
| 2646.436 | 3 | 37775.42 | |
| 2646.583 | 2 | 37773.32 | $4p\ ^4G^\circ_{2\frac{1}{2}} - s^2\ ^2F_{3\frac{1}{2}}$ |
| 2646.895 | 200 | 37768.87 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 5s\ ^4F_{3\frac{1}{2}}$ |
| 2648.719 | 10 | 37742.86 | $4s\ ^2F_{2\frac{1}{2}} - 4p\ ^4D^\circ_{2\frac{1}{2}}$ |
| 2649.436 | 40 | 37732.65 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 5s''\ ^4P_{2\frac{1}{2}}$ |
| 2649.710 | 1 | 37728.75 | |
| 2650.856 | 10 | 37712.44 | $s^2\ ^4F_{3\frac{1}{2}} - z\ ^6G^\circ_{4\frac{1}{2}}$ |
| 2651.408 | 1 | 37704.58 | $s^2\ ^4P_{1\frac{1}{2}} - 5p\ ^2D^\circ_{2\frac{1}{2}}$ |
| | | | $z\ ^4D^\circ_{2\frac{1}{2}} - 7d\ ^4D_{2\frac{1}{2}}$ |
| 2654.392 | 1 | 37662.20 | $5s\ ^4F_{3\frac{1}{2}} - t\ ^4D^\circ_{2\frac{1}{2}}$ |
| 2654.460 | 3 | 37661.24 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 5s''\ ^4P_{2\frac{1}{2}}$ |
| 2655.345 | 150 | 37648.69 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 5s\ ^2F_{2\frac{1}{2}}$ |
| 2655.769 | 150 | 37642.67 | $4p\ ^4F^\circ_{1\frac{1}{2}} - 5s\ ^4F_{1\frac{1}{2}}$ |
| 2659.498 | 150 | 37589.90 | $4p''\ ^4D^\circ_{3\frac{1}{2}} - 5s''\ ^4P_{2\frac{1}{2}}$ |
| 2661.006 | 1 | 37568.60 | |
| 2663.220 | 3 | 37537.37 | $4p\ ^4G^\circ_{3\frac{1}{2}} - 5s\ ^4F_{4\frac{1}{2}}$ |
| 2665.252 | 50 | 37508.75 | $4s''\ ^2P_{1\frac{1}{2}} - 4p''\ ^4P^\circ_{1\frac{1}{2}}$ |
| 2665.852 | 15 | 37500.31 | $4s''\ ^2P_{1\frac{1}{2}} - 4p''\ ^4P^\circ_{2\frac{1}{2}}$ |
| 2665.950 | 100 | 37498.93 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 5s''\ ^2P_{1\frac{1}{2}}$ |
| 2666.423 | 50 | 37492.28 | $4p\ ^2G^\circ_{4\frac{1}{2}} - s^2\ ^2F_{3\frac{1}{2}}$ |
| 2666.616 | 2 | 37489.56 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 4d'\ ^2D_{2\frac{1}{2}}$ |
| 2669.211 | 15 | 37453.12 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 5s\ ^2F_{3\frac{1}{2}}$ |
| 2669.365 | 1 | 37450.96 | $4p'''\ ^2H^\circ_{5\frac{1}{2}} - 4d'\ ^2G_{4\frac{1}{2}}$? |
| 2670.326 | 30 | 37437.48 | $4s''\ ^2P_{0\frac{1}{2}} - 4p''\ ^4P^\circ_{0\frac{1}{2}}$ |
| 2673.207 | 40 | 37397.14 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 5s'\ ^2D_{1\frac{1}{2}}$ |
| 2674.848 | 50 | 37374.19 | $4p\ ^4F^\circ_{3\frac{1}{2}} - s^2\ ^2F_{3\frac{1}{2}}$ |
| 2676.231 | 2 | 37354.88 | $4p\ ^4G^\circ_{2\frac{1}{2}} - s^2\ ^2F_{2\frac{1}{2}}$ |
| 2679.109 | 200 | 37314.76 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 5s\ ^4F_{2\frac{1}{2}}$ |
| 2679.521 | 30 | 37309.02 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 5s\ ^2F_{2\frac{1}{2}}$ |
| 2679.659 | 5 | 37307.10 | $4p\ ^4G^\circ_{2\frac{1}{2}} - 5s\ ^4F_{3\frac{1}{2}}$ |
| 2680.153 | 75 | 37300.22 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 5s''\ ^2P_{0\frac{1}{2}}$ |
| 2680.310 | 2 | 37298.04 | |
| 2681.376 | 3 | 37283.21 | $s^2\ ^4P_{1\frac{1}{2}} - 5p\ ^4D^\circ_{1\frac{1}{2}}$ |
| 2682.194 | 100 | 37271.84 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 5s'\ ^2D_{2\frac{1}{2}}$ |
| 2682.782 | 5 | 37263.67 | |
| 2683.385 | 30 | 37255.30 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 4d'\ ^2G_{4\frac{1}{2}}$ |
| 2684.277 | 300 | 37242.92 | $4p\ ^4F^\circ_{4\frac{1}{2}} - 5s\ ^4F_{4\frac{1}{2}}$ |
| 2684.680 | 10 | 37237.33 | $s^2\ ^4F_{2\frac{1}{2}} - z\ ^6G^\circ_{3\frac{1}{2}}$ |
| 2688.881 | 5 | 37179.15 | |
| 2689.730 | 50 | 37167.42 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 5s'\ ^2D_{1\frac{1}{2}}$ |
| 2690.178 | 3 | 37161.23 | $4d\ ^4D_{3\frac{1}{2}} - 6f\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2690.485 | 150 | 37156.99 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 5s\ ^2F_{3\frac{1}{2}}$ |
| 2690.925 | 1 | 37150.91 | $4p'''\ ^2G^\circ_{4\frac{1}{2}} - 6s\ ^4F_{3\frac{1}{2}}$ |
| 2692.697 | 3 | 37126.47 | $s^2\ ^4F_{4\frac{1}{2}} - z\ ^6D^\circ_{4\frac{1}{2}}$ |
| 2698.823 | 50 | 37042.20 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 5s'\ ^2D_{2\frac{1}{2}}$ |
| 2699.994 | 20 | 37026.13 | $4p\ ^2G^\circ_{4\frac{1}{2}} - 5s\ ^4F_{3\frac{1}{2}}$ |
| 2702.796 | 3 | 36987.75 | $4d\ ^4D_{2\frac{1}{2}} - 6f\ ^2G^\circ_{3\frac{1}{2}}$ |
| 2702.905 | 4 | 36986.26 | $4s''\ ^2P_{0\frac{1}{2}} - 4p''\ ^4P^\circ_{1\frac{1}{2}}$ |
| 2704.248 | 3 | 36967.89 | $4d\ ^4D_{3\frac{1}{2}} - 4f''\ ^4F^\circ_{4\frac{1}{2}}$ |
| 2704.415 | 20 | 36965.61 | $4p\ ^4F^\circ_{1\frac{1}{2}} - 5s\ ^4F_{2\frac{1}{2}}$ |
| 2705.154 | 3 | 36955.51 | $4p\ ^4F^\circ_{3\frac{1}{2}} - s^2\ ^2F_{2\frac{1}{2}}$ |
| 2707.390 | 3 | 36924.99 | $s^2\ ^4F_{1\frac{1}{2}} - z\ ^6G^\circ_{2\frac{1}{2}}$ |
| 2708.635 | 200 | 36908.02 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 5s\ ^4F_{3\frac{1}{2}}$ |
| 2709.636 | 50 | 36894.39 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 5s''\ ^2P_{1\frac{1}{2}}$ |
| 2716.434 | 5 | 36802.06 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 4d'\ ^2F_{3\frac{1}{2}}$ |
| 2718.239 | 5 | 36777.63 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 5s''\ ^4P_{1\frac{1}{2}}$? |
| 2718.392 | 15 | 36775.56 | $4p'''\ ^2F^\circ_{2\frac{1}{2}} - 4d'\ ^2G_{3\frac{1}{2}}$ |
| 2721.770 | 3 | 36729.92 | $s^2\ ^4P_{0\frac{1}{2}} - 5p\ ^4D^\circ_{1\frac{1}{2}}$ |
| 2722.738 | 10 | 36716.86 | $4p\ ^4F^\circ_{2\frac{1}{2}} - s^2\ ^2F_{3\frac{1}{2}}$ |
| 2724.165 | 3 | 36697.63 | |
| 2724.725 | 50 | 36690.08 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 5s''\ ^2P_{0\frac{1}{2}}$ |
| 2727.943 | 1 | 36646.81 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 5s\ ^4F_{1\frac{1}{2}}$ |
| 2728.683 | 3 | 36636.87 | $4d\ ^4H_{5\frac{1}{2}} - 6f\ ^4I^\circ_{5\frac{1}{2}}$ |
| 2729.712 | 3 | 36623.06 | $s^2\ ^4P_{2\frac{1}{2}} - 5p\ ^4D^\circ_{2\frac{1}{2}}$ |
| 2731.517 | 3 | 36598.86 | |
| 2731.642 | 5 | 36597.18 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 5s''\ ^4P_{2\frac{1}{2}}$ |
| 2732.708 | 3 | 36582.91 | $4d\ ^4P_{1\frac{1}{2}} - 6f\ ^2P^\circ_{1\frac{1}{2}}$ |
| 2737.678 | 3 | 36516.50 | |
| 2738.890 | 20 | 36500.34 | $4p\ ^2G^\circ_{4\frac{1}{2}} - 5s\ ^4F_{4\frac{1}{2}}$ |
| 2739.649 | 2 | 36490.23 | $4d\ ^4F_{4\frac{1}{2}} - 6f\ ^2H^\circ_{5\frac{1}{2}}$ |
| 2739.761 | 3 | 36488.74 | |
| 2742.359 | 3 | 36454.17 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 4d\ ^2D_{2\frac{1}{2}}$ |
| 2742.489 | 3 | 36452.44 | $4d\ ^2P_{1\frac{1}{2}} - 6f\ ^4F^\circ_{1\frac{1}{2}}$ |
| | | | $4d\ ^4P_{1\frac{1}{2}} - 4f''\ ^4F^\circ_{1\frac{1}{2}}$ |
| 2742.831 | 300 | 36447.90 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 5s\ ^2F_{3\frac{1}{2}}$ |
| 2747.780 | 15 | 36382.26 | $4p\ ^4F^\circ_{3\frac{1}{2}} - 5s\ ^4F_{4\frac{1}{2}}$ |
| 2747.920 | 2 | 36380.40 | |
| 2750.475 | 5 | 36346.61 | $s^2\ ^4P_{1\frac{1}{2}} - 5p\ ^4D^\circ_{2\frac{1}{2}}$ |
| 2753.285 | 10 | 36309.52 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 5s\ ^4F_{2\frac{1}{2}}$ |
| 2754.929 | 2 | 36287.85 | $4d\ ^4F_{3\frac{1}{2}} - 6f\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2755.208 | 75 | 36284.18 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 5s''\ ^2P_{1\frac{1}{2}}$ |
| 2757.761 | 20 | 36250.59 | $4p\ ^4F^\circ_{2\frac{1}{2}} - 5s\ ^4F_{3\frac{1}{2}}$ |
| 2758.874 | 150 | 36235.96 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 5s\ ^2F_{2\frac{1}{2}}$ |
| 2760.671 | 15 | 36212.38 | $4s'''\ ^2G_{3\frac{1}{2}} - 4p'\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2761.452 | 2 | 36202.14 | $4d\ ^4G_{4\frac{1}{2}} - 6f\ ^2H^\circ_{5\frac{1}{2}}$ |
| 2761.805 | 1 | 36197.51 | $4d\ ^4G_{4\frac{1}{2}} - 6f\ ^4H^\circ_{4\frac{1}{2}}$ |
| 2762.726 | 1 | 36185.44 | $4d\ ^4G_{4\frac{1}{2}} - 6f\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2763.440 | 5 | 36176.09 | $4d\ ^4H_{4\frac{1}{2}} - 6f\ ^2I^\circ_{5\frac{1}{2}}$ |
| 2764.412 | 8 | 36163.38 | $4d\ ^4G_{4\frac{1}{2}} - 6f\ ^4I^\circ_{5\frac{1}{2}}$ |
| 2768.634 | 150 | 36108.23 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 5s\ ^2F_{3\frac{1}{2}}$ |
| 2771.473 | 10 | 36071.25 | $4d\ ^4D_{2\frac{1}{2}} - 6f\ ^2D^\circ_{2\frac{1}{2}}$ |
| | | | $4d\ ^2F_{3\frac{1}{2}} - 6f\ ^2G^\circ_{3\frac{1}{2}}$ |
| 2771.567 | 8 | 36070.02 | $4d\ ^4D_{2\frac{1}{2}} - 6f\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2772.018 | 5 | 36064.15 | $4d\ ^4D_{2\frac{1}{2}} - 6f\ ^2P^\circ_{1\frac{1}{2}}$ |
| 2772.090 | 5 | 36063.22 | $4d\ ^4D_{2\frac{1}{2}} - 6f\ ^4G^\circ_{3\frac{1}{2}}$ |
| 2772.296 | 3 | 36060.54 | $4d\ ^4D_{2\frac{1}{2}} - 6f\ ^4D^\circ_{1\frac{1}{2}}$ |
| 2773.435 | 8 | 36045.73 | |
| 2773.856 | 15 | 36040.26 | $4d\ ^4D_{1\frac{1}{2}} - 6f\ ^4F^\circ_{1\frac{1}{2}}$ |
| 2774.938 | 8 | 36026.21 | $4d\ ^4D_{1\frac{1}{2}} - 6f\ ^4D^\circ_{0\frac{1}{2}}$ |
| 2775.160 | 150 | 36023.32 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 5s\ ^2F_{2\frac{1}{2}}$ |
| 2776.349 | 1 | 36007.90 | |
| 2776.806 | 40 | 36001.97 | $4p\ ^2G^\circ_{3\frac{1}{2}} - s^2\ ^2F_{2\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 2779.288 | 8 | 35969.82 | $4p\ ^2D^\circ_{2\frac{1}{2}} - 5s\ ^4F_{2\frac{1}{2}}$ |
| 2779.360 | 3 | 35968.89 | $4p'\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^2D_{1\frac{1}{2}}$ |
| 2779.591 | 5 | 35965.90 | $s^2\ ^4F_{3\frac{1}{2}} - z\ ^6D^\circ_{4\frac{1}{2}}$ |
| 2780.482 | 30 | 35954.38 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 5s\ ^4F_{3\frac{1}{2}}$ |
| 2780.551 | 10 | 35953.48 | $4d\ ^4G_{3\frac{1}{2}} - 6f\ ^2H^\circ_{4\frac{1}{2}}$ |
| 2780.905 | 10 | 35948.91 | $4p\ ^4F^\circ_{1\frac{1}{2}} - s^2\ ^2F_{2\frac{1}{2}}$ |
| 2782.258 | 5 | 35931.43 | $4d\ ^4G_{3\frac{1}{2}} - 6f\ ^4I^\circ_{4\frac{1}{2}}$ |
| 2782.947 | 1 | 35922.53 | $s^2\ ^4F_{3\frac{1}{2}} - z\ ^6F^\circ_{2\frac{1}{2}}$ |
| 2785.861 | 2 | 35884.96 | $4d\ ^4D_{2\frac{1}{2}} - 4f''\ ^4F^\circ_{3\frac{1}{2}}$? |
| 2790.557 | 15 | 35824.57 | $s^2\ ^4F_{4\frac{1}{2}} - z\ ^6F^\circ_{4\frac{1}{2}}$ |
| 2792.133 | 50 | 35804.35 | $4d\ ^4D_{3\frac{1}{2}} - 6f\ ^4F^\circ_{4\frac{1}{2}}$ |
| 2792.872 | 50 | 35794.88 | $4d\ ^4D_{3\frac{1}{2}} - 6f\ ^4D^\circ_{3\frac{1}{2}}$ |
| 2793.344 | 40 | 35788.83 | $4d\ ^4D_{3\frac{1}{2}} - 6f\ ^4P^\circ_{2\frac{1}{2}}$ |
| 2793.597 | 20 | 35785.59 | $4d\ ^4D_{3\frac{1}{2}} - 6f\ ^4F^\circ_{3\frac{1}{2}}$ |
| 2794.621 | 100 | 35772.48 | $4p''\ ^2P^\circ_{0\frac{1}{2}} - 5s''\ ^2P_{0\frac{1}{2}}$ |
| 2795.139 | 3 | 35765.85 | |
| 2799.251 | 3 | 35713.31 | |
| 2799.390 | 20 | 35711.54 | $4p\ ^2F^\circ_{3\frac{1}{2}} - s^2\ ^2F_{3\frac{1}{2}}$ |
| 2799.559 | 5 | 35709.39 | |
| 2800.230 | 15 | 35700.83 | $4d\ ^4P_{2\frac{1}{2}} - 6f\ ^4D^\circ_{3\frac{1}{2}}$ |
| 2800.701 | 40 | 35694.83 | $4d\ ^4P_{2\frac{1}{2}} - 6f\ ^4P^\circ_{2\frac{1}{2}}$ |
| 2800.807 | 40 | 35693.48 | $4d\ ^4P_{2\frac{1}{2}} - 6f\ ^4S^\circ_{1\frac{1}{2}}$ |
| 2800.950 | 1 | 35691.65 | $4d\ ^4P_{2\frac{1}{2}} - 6f\ ^4F^\circ_{3\frac{1}{2}}$ |
| 2801.199 | 15 | 35688.48 | $4d\ ^4P_{2\frac{1}{2}} - 6f\ ^4P^\circ_{1\frac{1}{2}}$ |
| 2801.711 | 1 | 35681.96 | |
| 2801.775 | 15 | 35681.14 | |
| 2802.510 | 10 | 35671.79 | $4d\ ^4D_{0\frac{1}{2}} - 6f\ ^4D^\circ_{0\frac{1}{2}}$ |
| 2803.916 | 3 | 35653.90 | |
| 2804.768 | 3 | 35643.07 | |
| 2805.668 | 60 | 35631.64 | $4s'''\ ^2G_{4\frac{1}{2}} - 4p'\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2806.236 | 8 | 35624.43 | $s^2\ ^2G_{3\frac{1}{2}} - 5p\ ^2F^\circ_{2\frac{1}{2}}$ |
| 2806.719 | 5 | 35618.30 | |
| 2807.083 | 10d | 35613.68 | $4d\ ^4P_{0\frac{1}{2}} - 6f\ ^2P^\circ_{1\frac{1}{2}}$? |
| 2807.388 | 3 | 35609.81 | $4d\ ^4P_{0\frac{1}{2}} - 6f\ ^4D^\circ_{1\frac{1}{2}}$ |
| 2807.560 | 1 | 35607.63 | $4s'''\ ^2G_{3\frac{1}{2}} - 4p'\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2808.343 | 20 | 35597.70 | $4s'\ ^2D_{2\frac{1}{2}} - 4p\ ^2D^\circ_{1\frac{1}{2}}$ |
| 2809.044 | 10 | 35588.82 | $4d\ ^4P_{0\frac{1}{2}} - 6f\ ^4P^\circ_{0\frac{1}{2}}$ |
| 2810.221 | 10 | 35573.91 | $4p\ ^2F^\circ_{2\frac{1}{2}} - 5s\ ^4F_{1\frac{1}{2}}$ |
| 2811.092 | 10 | 35562.89 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 5s''\ ^4P_{1\frac{1}{2}}$ |
| 2811.207 | 3 | 35561.43 | |
| 2811.331 | 2 | 35559.87 | $z\ ^2F^\circ_{3\frac{1}{2}} - 7d\ ^4D_{2\frac{1}{2}}$ |
| 2811.960 | 10 | 35551.91 | $4d\ ^2P_{1\frac{1}{2}} - 6f\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2812.521 | 20 | 35544.82 | $4d\ ^2P_{1\frac{1}{2}} - 6f\ ^2P^\circ_{1\frac{1}{2}}$ |
| 2812.582 | 5 | 35544.05 | $s^2\ ^4F_{2\frac{1}{2}} - z\ ^6F^\circ_{1\frac{1}{2}}$ |
| 2814.469 | 8 | 35520.22 | $4d\ ^2P_{1\frac{1}{2}} - 6f\ ^4P^\circ_{0\frac{1}{2}}$ |
| 2815.341 | 8 | 35509.22 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^2D_{1\frac{1}{2}}$ |
| 2815.980 | 5 | 35501.16 | |
| 2816.256 | 1 | 35497.68 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 5s'\ ^2D_{1\frac{1}{2}}$ |
| 2817.407 | 2h | 35483.18 | $4d\ ^4P_{0\frac{1}{2}} - 4f''\ ^4F^\circ_{1\frac{1}{2}}$? |
| 2817.722 | 8 | 35479.22 | $s^2\ ^2G_{4\frac{1}{2}} - 5p\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2819.882 | 5 | 35452.04 | $4d\ ^4H_{6\frac{1}{2}} - 6f\ ^4G^\circ_{5\frac{1}{2}}$ |
| 2820.472 | 40 | 35444.62 | $4d\ ^4H_{6\frac{1}{2}} - 6f\ ^4H^\circ_{6\frac{1}{2}}$ |
| 2821.745 | 150 | 35428.64 | $4p\ ^2G^\circ_{3\frac{1}{2}} - 5s\ ^4F_{4\frac{1}{2}}$<br>$4d\ ^4H_{6\frac{1}{2}} - 6f\ ^4I^\circ_{7\frac{1}{2}}$ |
| 2822.879 | 2 | 35414.40 | $4d\ ^2P_{1\frac{1}{2}} - 4f''\ ^4F^\circ_{1\frac{1}{2}}$ |
| 2823.877 | 2 | 35401.89 | $4d\ ^4H_{3\frac{1}{2}} - 6f\ ^2H^\circ_{4\frac{1}{2}}$ |
| 2824.214 | 8 | 35397.66 | $4d\ ^4H_{3\frac{1}{2}} - 6f\ ^4H^\circ_{3\frac{1}{2}}$ |
| 2825.142 | 3 | 35386.04 | |
| 2825.231 | 15 | 35384.92 | $4s'\ ^2D_{2\frac{1}{2}} - 4p\ ^2F^\circ_{2\frac{1}{2}}$ |
| 2825.416 | 1 | 35382.60 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 5s''\ ^4P_{2\frac{1}{2}}$?<br>$4d\ ^2P_{1\frac{1}{2}} - 4f''\ ^4F^\circ_{2\frac{1}{2}}$? |
| 2825.477 | 1 | 35381.84 | $4p'\ ^2P^\circ_{0\frac{1}{2}} - 4d\ ^2D_{1\frac{1}{2}}$ |
| 2825.641 | 50 | 35379.79 | $4d\ ^4H_{3\frac{1}{2}} - 6f\ ^4I^\circ_{4\frac{1}{2}}$ |
| 2826.043 | 3 | 35374.76 | $4p''\ ^4S^\circ_{1\frac{1}{2}} - 5s''\ ^2P_{0\frac{1}{2}}$ |
| 2826.270 | 20 | 35371.91 | $4p\ ^2D^\circ_{2\frac{1}{2}} - s^2\ ^2F_{3\frac{1}{2}}$ |
| 2826.693 | 1 | 35366.62 | $4p''\ ^2P^\circ_{0\frac{1}{2}} - 5s''\ ^2P_{1\frac{1}{2}}$ |
| 2827.126 | 10 | 35361.21 | $4p\ ^2D^\circ_{1\frac{1}{2}} - 5s\ ^4F_{1\frac{1}{2}}$ |
| 2827.507 | 5 | 35356.44 | $4d\ ^4F_{2\frac{1}{2}} - 4f''\ ^2D^\circ_{1\frac{1}{2}}$ |
| 2829.452 | 3 | 35332.14 | $s^2\ ^4F_{3\frac{1}{2}} - z\ ^6F^\circ_{3\frac{1}{2}}$ |
| 2829.545 | 1 | 35330.98 | $4p'\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^2D_{2\frac{1}{2}}$ |
| 2830.496 | 2 | 35319.11 | $4d\ ^2H_{5\frac{1}{2}} - 6f\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2830.675 | 4 | 35316.87 | $4d\ ^4H_{5\frac{1}{2}} - 6f\ ^4G^\circ_{4\frac{1}{2}}$ |
| 2831.054 | 5 | 35312.15 | $4d\ ^4H_{5\frac{1}{2}} - 6f\ ^4H^\circ_{5\frac{1}{2}}$ |
| 2831.354 | 15 | 35308.40 | $4d\ ^4H_{4\frac{1}{2}} - 6f\ ^4H^\circ_{4\frac{1}{2}}$ |
| 2831.622 | 30 | 35305.06 | $4d\ ^4H_{5\frac{1}{2}} - 6f\ ^4G^\circ_{5\frac{1}{2}}$ |
| 2831.861 | 3 | 35302.08 | $4d\ ^4H_{5\frac{1}{2}} - 6f\ ^4F^\circ_{4\frac{1}{2}}$ |
| 2831.937 | 5 | 35301.13 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 5s'\ ^2D_{2\frac{1}{2}}$<br>$4d\ ^2F_{2\frac{1}{2}} - 6f\ ^4G^\circ_{2\frac{1}{2}}$ |
| 2832.050 | 10 | 35299.73 | $4d\ ^2F_{2\frac{1}{2}} - 6f\ ^2G^\circ_{3\frac{1}{2}}$ |
| 2832.209 | 50 | 35297.74 | $4d\ ^4H_{5\frac{1}{2}} - 6f\ ^4H^\circ_{6\frac{1}{2}}$<br>$s^2\ ^4F_{4\frac{1}{2}} - z\ ^6F^\circ_{5\frac{1}{2}}$ |
| 2832.267 | 200 | 35297.02 | $4d\ ^2H_{5\frac{1}{2}} - 6f\ ^2I^\circ_{6\frac{1}{2}}$ |
| 2832.444 | 2 | 35294.82 | $4d\ ^2F_{2\frac{1}{2}} - 6f\ ^4H^\circ_{3\frac{1}{2}}$ |
| 2832.791 | 15 | 35290.49 | $4d\ ^4H_{4\frac{1}{2}} - 6f\ ^4G^\circ_{3\frac{1}{2}}$<br>$4d\ ^4F_{1\frac{1}{2}} - 6f\ ^4G^\circ_{2\frac{1}{2}}$ |
| 2833.321 | 8 | 35283.89 | $4d\ ^2F_{2\frac{1}{2}} - 6f\ ^4F^\circ_{1\frac{1}{2}}$ |
| 2833.602 | 2 | 35280.39 | $s^2\ ^4F_{1\frac{1}{2}} - z\ ^6F^\circ_{0\frac{1}{2}}$ |
| 2833.699 | 1 | 35279.19 | |
| 2834.110 | 100 | 35274.07 | $4d\ ^4H_{4\frac{1}{2}} - 6f\ ^4I^\circ_{5\frac{1}{2}}$ |
| 2834.172 | 5 | 35273.30 | $4d\ ^4F_{1\frac{1}{2}} - 6f\ ^4F^\circ_{1\frac{1}{2}}$ |
| 2834.354 | 5 | 35271.03 | $4d\ ^2P_{0\frac{1}{2}} - 6f\ ^4D^\circ_{0\frac{1}{2}}$<br>$4d\ ^2H_{5\frac{1}{2}} - 4f''\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2834.525 | 100 | 35268.91 | $4d\ ^4H_{5\frac{1}{2}} - 6f\ ^4I^\circ_{6\frac{1}{2}}$ |
| 2835.060 | 100 | 35262.25 | $4p'''\ ^2G^\circ_{3\frac{1}{2}} - 5s'''\ ^2G_{3\frac{1}{2}}$ |
| 2835.703 | 10 | 35254.25 | $4d\ ^4P_{1\frac{1}{2}} - 6f\ ^4D^\circ_{2\frac{1}{2}}$ |
| 2835.816 | 10 | 35252.85 | |
| 2836.195 | 2 | 35248.14 | $4d\ ^4H_{4\frac{1}{2}} - 4f''\ ^2G^\circ_{4\frac{1}{2}}$ |
| 2836.425 | 75 | 35245.28 | $4p\ ^2F^\circ_{3\frac{1}{2}} - 5s\ ^4F_{3\frac{1}{2}}$ |
| 2836.612 | 1 | 35242.96 | |
| 2836.758 | 2 | 35241.14 | $4d\ ^4F_{2\frac{1}{2}} - 6f\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2836.857 | 15 | 35239.92 | $4d\ ^4F_{2\frac{1}{2}} - 6f\ ^2F^\circ_{3\frac{1}{2}}$ |
| 2837.415 | 20 | 35232.98 | $4d\ ^4F_{2\frac{1}{2}} - 6f\ ^4G^\circ_{3\frac{1}{2}}$ |
| 2837.632 | 3 | 35230.29 | $4d\ ^4F_{2\frac{1}{2}} - 6f\ ^4D^\circ_{1\frac{1}{2}}$ |
| 2837.680 | 3 | 35229.69 | $4p''\ ^4D^\circ_{3\frac{1}{2}} - 5s'\ ^2D_{2\frac{1}{2}}$ |
| 2837.769 | 30 | 35228.59 | $4d\ ^4F_{2\frac{1}{2}} - 6f\ ^4F^\circ_{2\frac{1}{2}}$ |
| 2839.353 | 20 | 35208.94 | $4d\ ^4P_{1\frac{1}{2}} - 6f\ ^4P^\circ_{1\frac{1}{2}}$ |
| 2840.168 | 2 | 35198.83 | |
| 2840.472 | 20 | 35195.07 | |
| 2840.930 | 20 | 35189.39 | $4d\ ^2H_{4\frac{1}{2}} - 6f\ ^2H^\circ_{4\frac{1}{2}}$ |
| 2841.496 | 5 | 35182.39 | $4d\ ^4G_{2\frac{1}{2}} - 6f\ ^4G^\circ_{2\frac{1}{2}}$ |
| 2841.611 | 8 | 35180.96 | $4d\ ^4G_{2\frac{1}{2}} - 6f\ ^2G^\circ_{3\frac{1}{2}}$ |
| 2842.002 | 40 | 35176.12 | $4d\ ^4G_{2\frac{1}{2}} - 6f\ ^4H^\circ_{3\frac{1}{2}}$ |
| 2842.417 | 50 | 35170.99 | $4s'''\ ^2G_{3\frac{1}{2}} - 4p'\ ^2F^\circ_{2\frac{1}{2}}$ |
| 2842.701 | 2 | 35167.47 | $4d\ ^2H_{4\frac{1}{2}} - 6f\ ^4I^\circ_{4\frac{1}{2}}$? |
| 2842.906 | 10 | 35164.94 | |
| 2842.929 | 30 | 35164.65 | $4d\ ^2F_{3\frac{1}{2}} - 6f\ ^4H^\circ_{4\frac{1}{2}}$ |
| 2843.189 | 5 | 35161.44 | $4p'''\ ^2G^\circ_{4\frac{1}{2}} - 5s'''\ ^2G_{3\frac{1}{2}}$ |
| 2843.520 | 75 | 35157.34 | $4p'''\ ^2G^\circ_{4\frac{1}{2}} - 5s'''\ ^2G_{4\frac{1}{2}}$ |
| 2843.731 | 5 | 35154.74 | $4d\ ^2F_{3\frac{1}{2}} - 6f\ ^2D^\circ_{2\frac{1}{2}}$ |
| 2843.827 | 30 | 35153.55 | $4d\ ^2F_{3\frac{1}{2}} - 6f\ ^2F^\circ_{3\frac{1}{2}}$<br>$4d\ ^4G_{5\frac{1}{2}} - 6f\ ^4G^\circ_{4\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 2843.904 | 20 | 35152.60 | $4d\,^2F_{3\frac{1}{2}} - 6f\,^2G^\circ_{4\frac{1}{2}}$ |
| 2844.032 | 75 | 35151.02 | $4d\,^2H_{4\frac{1}{2}} - 6f\,^2\,I^\circ_{5\frac{1}{2}}$ |
| 2844.032 | 75 | 35151.02 | $4d\,^2H_{4\frac{1}{2}} - 6f\,^2\,I^\circ_{5\frac{1}{2}}$ |
| 2844.206 | 30 | 35148.86 | $4d\,^4G_{5\frac{1}{2}} - 6f\,^4H^\circ_{5\frac{1}{2}}$ |
| 2844.777 | 20 | 35141.81 | $4d\,^4G_{5\frac{1}{2}} - 6f\,^4G^\circ_{5\frac{1}{2}}$ |
| 2845.023 | 10 | 35138.77 | $4d\,^4G_{5\frac{1}{2}} - 6f\,^4F^\circ_{4\frac{1}{2}}$ |
| 2845.377 | 75 | 35134.40 | $4d\,^4G_{5\frac{1}{2}} - 6f\,^4H^\circ_{6\frac{1}{2}}$ |
| 2845.498 | 5 | 35132.91 | |
| 2845.601 | 15 | 35131.63 | $4d\,^4F_{4\frac{1}{2}} - 6f\,^4G^\circ_{4\frac{1}{2}}$ |
| 2845.815 | 10 | 35128.99 | $4d\,^4D_{1\frac{1}{2}} - 6f\,^4D^\circ_{1\frac{1}{2}}$ |
| 2845.991 | 5 | 35126.82 | $4d\,^4F_{4\frac{1}{2}} - 6f\,^4H^\circ_{5\frac{1}{2}}$ |
| 2846.562 | 50 | 35119.77 | $4d\,^4F_{4\frac{1}{2}} - 6f\,^4G^\circ_{5\frac{1}{2}}$ |
| 2846.803 | 50 | 35116.80 | $4d\,^4F_{4\frac{1}{2}} - 6f\,^4F^\circ_{4\frac{1}{2}}$ |
| 2847.581 | 20 | 35107.21 | $4d\,^4F_{4\frac{1}{2}} - 6f\,^4D^\circ_{3\frac{1}{2}}$ |
| 2847.706 | 40 | 35105.67 | $4d\,^4G_{5\frac{1}{2}} - 6f\,^4\,I^\circ_{6\frac{1}{2}}$ |
| 2848.329 | 2 | 35097.99 | $4d\,^4F_{4\frac{1}{2}} - 6f\,^4F^\circ_{3\frac{1}{2}}$ |
| 2848.921 | 3 | 35090.70 | $s^2\,^4F_{2\frac{1}{2}} - z\,^6F^\circ_{2\frac{1}{2}}$ |
| 2849.552 | 10 | 35082.93 | |
| 2852.433 | 50 | 35047.49 | $4d\,^4G_{3\frac{1}{2}} - 6f\,^4H^\circ_{4\frac{1}{2}}$ |
| 2853.032 | 10 | 35040.13 | |
| 2853.407 | 50 | 35035.53 | $4d\,^4G_{3\frac{1}{2}} - 6f\,^2G^\circ_{4\frac{1}{2}}$ |
| 2853.439 | 25 | 35035.14 | $4p\,^2F^\circ_{2\frac{1}{2}} - 5s\,^2F_{3\frac{1}{2}}$ |
| 2853.890 | 5 | 35029.60 | $4d\,^4G_{3\frac{1}{2}} - 6f\,^4G^\circ_{3\frac{1}{2}}$ |
| 2854.200 | 75 | 35025.80 | $4d\,^2G_{4\frac{1}{2}} - 6f\,^2H^\circ_{5\frac{1}{2}}$ |
| 2854.259 | 30 | 35025.07 | $4d\,^4G_{3\frac{1}{2}} - 6f\,^4F^\circ_{2\frac{1}{2}}$ |
| 2854.575 | 3 | 35021.20 | |
| 2855.481 | 8 | 35010.08 | $4d\,^2G_{4\frac{1}{2}} - 6f\,^2F^\circ_{3\frac{1}{2}}$ |
| 2855.557 | 30 | 35009.15 | $4d\,^2G_{4\frac{1}{2}} - 6f\,^2G^\circ_{4\frac{1}{2}}$ |
| 2856.260 | 5 | 35000.54 | |
| 2856.398 | 8 | 34998.85 | |
| 2857.408 | 100 | 34986.48 | $4p''\,^2S^\circ_{0\frac{1}{2}} - 5s''\,^2P_{1\frac{1}{2}}$ |
| 2857.870 | 1 | 34980.82 | $s^2\,^4F_{1\frac{1}{2}} - z\,^6F^\circ_{1\frac{1}{2}}$ |
| 2858.839 | 15 | 34968.96 | $4p''\,^4S^\circ_{1\frac{1}{2}} - 5s''\,^2P_{1\frac{1}{2}}$ |
| 2859.101 | 3 | 34965.76 | |
| 2859.492 | 20 | 34960.98 | $4d\,^2G_{4\frac{1}{2}} - 4f''\,^2G^\circ_{4\frac{1}{2}}$ |
| 2860.028 | 5 | 34954.43 | $4d\,^4F_{3\frac{1}{2}} - 6f\,^4D^\circ_{2\frac{1}{2}}$ |
| 2860.126 | 30 | 34953.23 | $4p\,^2D^\circ_{2\frac{1}{2}} - s^2\,^2F_{2\frac{1}{2}}$ |
| 2860.732 | 100 | 34945.83 | $4d\,^4F_{3\frac{1}{2}} - 6f\,^4G^\circ_{4\frac{1}{2}}$ |
| 2861.385 | 2 | 34937.85 | |
| 2862.723 | 20 | 34921.52 | $4d\,^4F_{3\frac{1}{2}} - 6f\,^4D^\circ_{3\frac{1}{2}}$ |
| 2863.214 | 3 | 34915.53 | $4d\,^4F_{3\frac{1}{2}} - 6f\,^4F^\circ_{2\frac{1}{2}}$ |
| 2863.482 | 30 | 34912.27 | $4d\,^4F_{3\frac{1}{2}} - 6f\,^4F^\circ_{3\frac{1}{2}}$ |
| 2863.699 | 100 | 34909.62 | $4s'\,^2D_{1\frac{1}{2}} - 4p\,^2D^\circ_{1\frac{1}{2}}$ |
| 2864.024 | 500 | 34905.66 | $4p\,^2D^\circ_{2\frac{1}{2}} - 5s\,^4F_{3\frac{1}{2}}$ |
| 2864.750 | 10 | 34896.81 | $4p\,^2F^\circ_{2\frac{1}{2}} - 5s\,^4F_{2\frac{1}{2}}$ |
| 2864.954 | 5 | 34894.33 | $4p'\,^2F^\circ_{3\frac{1}{2}} - 4d\,^2D_{2\frac{1}{2}}$ |
| 2866.526 | 3 | 34875.19 | $4d\,^2F_{2\frac{1}{2}} - 4f''\,^2F^\circ_{2\frac{1}{2}}$ |
| 2866.848 | 5 | 34871.28 | $4p'\,^2D^\circ_{1\frac{1}{2}} - 4d\,^2D_{2\frac{1}{2}}$ |
| 2867.137 | 3 | 34867.76 | |
| 2867.774 | 4 | 34860.02 | $4p''\,^2P^\circ_{0\frac{1}{2}} - 5s''\,^4P_{0\frac{1}{2}}$ |
| 2869.136 | 75 | 34843.47 | $4d\,^4G_{4\frac{1}{2}} - 6f\,^4G^\circ_{4\frac{1}{2}}$ |
| 2869.522 | 200 | 34838.78 | $4d\,^4G_{4\frac{1}{2}} - 6f\,^4H^\circ_{5\frac{1}{2}}$ |
| 2870.101 | 10 | 34831.75 | $4d\,^4G_{4\frac{1}{2}} - 6f\,^4G^\circ_{5\frac{1}{2}}$ |
| 2870.348 | 10 | 34828.76 | $4d\,^4G_{4\frac{1}{2}} - 6f\,^4F^\circ_{4\frac{1}{2}}$ |
| 2870.957 | 5 | 34821.37 | $4d\,^4D_{2\frac{1}{2}} - w\,^2G^\circ_{3\frac{1}{2}}$ |
| 2871.102 | 5 | 34819.61 | |
| 2871.898 | 8 | 34809.96 | $4d\,^4G_{4\frac{1}{2}} - 6f\,^4F^\circ_{3\frac{1}{2}}$ |
| 2872.153 | 20 | 34806.87 | $4d\,^2G_{3\frac{1}{2}} - 6f\,^2G^\circ_{3\frac{1}{2}}$ |
| 2872.208 | 100 | 34806.20 | $4d\,^2G_{3\frac{1}{2}} - 6f\,^2H^\circ_{4\frac{1}{2}}$ |
| 2872.562 | 3 | 34801.92 | $4d\,^2G_{3\frac{1}{2}} - 6f\,^4H^\circ_{3\frac{1}{2}}$ |
| 2878.045 | 20 | 34735.62 | $4d\,^4D_{2\frac{1}{2}} - 6f\,^4D^\circ_{2\frac{1}{2}}$ |
| 2879.382 | 10 | 34719.49 | $4p\,^2F^\circ_{3\frac{1}{2}} - 5s\,^4F_{4\frac{1}{2}}$ |
| 2880.781 | 1 | 34702.63 | $4d\,^4D_{2\frac{1}{2}} - 6f\,^4D^\circ_{3\frac{1}{2}}$ |
| 2881.188 | 5 | 34697.73 | $4p'\,^2P^\circ_{1\frac{1}{2}} - 4d\,^2D_{1\frac{1}{2}}$ |
| 2881.255 | 2 | 34696.92 | $4s'\,^2D_{1\frac{1}{2}} - 4p\,^2F^\circ_{2\frac{1}{2}}$ |
| 2881.543 | 15 | 34693.45 | $4d\,^4D_{2\frac{1}{2}} - 6f\,^4F^\circ_{3\frac{1}{2}}$ |
| 2882.317 | 50 | 34684.14 | $4p\,^2D^\circ_{1\frac{1}{2}} - 5s\,^4F_{2\frac{1}{2}}$ |
| 2882.832 | 2 | 34677.94 | |
| 2882.996 | 2 | 34675.97 | $4p''\,^4P^\circ_{2\frac{1}{2}} - 4d\,^2F_{2\frac{1}{2}}$ |
| 2883.811 | 8 | 34666.17 | |
| 2883.986 | 1 | 34664.06 | $s^2\,^4F_{3\frac{1}{2}} - z\,^6F^\circ_{4\frac{1}{2}}$ |
| 2885.253 | 8 | 34648.84 | $4d\,^4D_{2\frac{1}{2}} - w\,^2F^\circ_{2\frac{1}{2}}$? |
| 2889.703 | 3 | 34595.49 | |
| 2891.231 | 3 | 34577.21 | |
| 2896.604 | 3 | 34513.07 | |
| 2896.641 | 1 | 34512.63 | |
| 2898.050 | 5 | 34495.85 | $4d\,^4H_{3\frac{1}{2}} - 6f\,^4H^\circ_{4\frac{1}{2}}$ |
| 2898.234 | 1 | 34493.66 | $4d\,^2D_{2\frac{1}{2}} - 7f\,^4P^\circ_{2\frac{1}{2}}$ |
| 2900.862 | 50 | 34462.41 | $4p''\,^4S^\circ_{1\frac{1}{2}} - 5s''\,^4P_{0\frac{1}{2}}$ |
| 2905.963 | 2 | 34401.92 | $4d\,^4D_{3\frac{1}{2}} - 4f'\,^2F^\circ_{3\frac{1}{2}}$ |
| 2907.543 | 8 | 34383.23 | $4d\,^2F_{2\frac{1}{2}} - 6f\,^2D^\circ_{2\frac{1}{2}}$ |
| 2907.642 | 8 | 34382.06 | $4d\,^2F_{2\frac{1}{2}} - 6f\,^2F^\circ_{3\frac{1}{2}}$ |
| 2908.148 | 3 | 34376.08 | $4d\,^2F_{2\frac{1}{2}} - 6f\,^2F^\circ_{1\frac{1}{2}}$ |
| 2908.228 | 1 | 34375.13 | $4d\,^2F_{2\frac{1}{2}} - 6f\,^4G^\circ_{3\frac{1}{2}}$ |
| 2908.443 | 3 | 34372.59 | $4d\,^2F_{2\frac{1}{2}} - 6f\,^4D^\circ_{1\frac{1}{2}}$<br>$4d\,^4F_{1\frac{1}{2}} - 6f\,^2D^\circ_{2\frac{1}{2}}$ |
| 2908.599 | 3 | 34370.75 | |
| 2909.127 | 3 | 34364.51 | |
| 2909.328 | 5 | 34362.13 | $4p''\,^2D^\circ_{2\frac{1}{2}} - 5s'\,^2D_{1\frac{1}{2}}$ |
| 2913.590 | 100 | 34311.87 | $4s'\,^2D_{2\frac{1}{2}} - 4p\,^2D^\circ_{2\frac{1}{2}}$ |
| 2914.695 | 15 | 34298.86 | $4p\,^2F^\circ_{2\frac{1}{2}} - s^2\,^2F_{3\frac{1}{2}}$ |
| 2915.479 | 3 | 34289.64 | $4p'\,^2D^\circ_{2\frac{1}{2}} - 4d\,^2D_{2\frac{1}{2}}$ |
| 2915.646 | 8 | 34287.68 | $s^2\,^2G_{4\frac{1}{2}} - 5p\,^4F^\circ_{3\frac{1}{2}}$ |
| 2917.561 | 8 | 34265.17 | $4p''\,^2S^\circ_{0\frac{1}{2}} - 5s''\,^4P_{1\frac{1}{2}}$ |
| 2918.934 | 3 | 34249.06 | $4d\,^2H_{4\frac{1}{2}} - 6f\,^4\,I^\circ_{5\frac{1}{2}}$ |
| 2919.052 | 75 | 34247.67 | $4p''\,^4S^\circ_{1\frac{1}{2}} - 5s''\,^4P_{1\frac{1}{2}}$ |
| 2919.967 | 10 | 34236.94 | $4p''\,^2D^\circ_{2\frac{1}{2}} - 5s'\,^2D_{2\frac{1}{2}}$ |
| 2926.800 | 2 | 34157.01 | |
| 2931.622 | 10 | 34100.83 | $5p\,^4D^\circ_{3\frac{1}{2}} - 8d\,^4F_{4\frac{1}{2}}$ |
| 2934.516 | 100 | 34067.20 | $4p''\,^4S^\circ_{1\frac{1}{2}} - 5s''\,^4P_{2\frac{1}{2}}$ |
| 2935.092 | 5 | 34060.52 | $5p\,^4D^\circ_{2\frac{1}{2}} - 9s\,^2F_{3\frac{1}{2}}$ |
| 2935.149 | 5 | 34059.86 | $4p'\,^2P^\circ_{1\frac{1}{2}} - 4d\,^2D_{2\frac{1}{2}}$ |
| 2935.632 | 20 | 34054.25 | $5p\,^4D^\circ_{3\frac{1}{2}} - 8d\,^4D_{3\frac{1}{2}}$ |
| 2935.682 | 20 | 34053.67 | $5p\,^4D^\circ_{3\frac{1}{2}} - 8d\,^4P_{2\frac{1}{2}}$ |
| 2942.788 | 2 | 33971.45 | |
| 2947.454 | 40 | 33917.67 | $4s''\,^4P_{1\frac{1}{2}} - 4p\,^2D^\circ_{1\frac{1}{2}}$ |
| 2948.515 | 5 | 33905.47 | $4d\,^4F_{2\frac{1}{2}} - 6f\,^4D^\circ_{2\frac{1}{2}}$ |
| 2948.964 | 4 | 33900.31 | $4d\,^2G_{3\frac{1}{2}} - 6f\,^4H^\circ_{4\frac{1}{2}}$ |
| 2950.716 | 15 | 33880.18 | $4p\,^2F_{2\frac{1}{2}} - s^2\,^2F_{2\frac{1}{2}}$ |
| 2952.183 | 2 | 33863.34 | $4d\,^4F_{2\frac{1}{2}} - 6f\,^4F^\circ_{3\frac{1}{2}}$ |
| 2954.863 | 75 | 33832.63 | $4p\,^2F^\circ_{2\frac{1}{2}} - 5s\,^4F_{3\frac{1}{2}}$ |
| 2956.860 | 5 | 33809.78 | $4p''\,^4P^\circ_{1\frac{1}{2}} - 4d\,^4F_{2\frac{1}{2}}$ |
| 2959.638 | 2 | 33778.05 | |
| 2964.602 | 10 | 33721.49 | |
| 2966.368 | 2 | 33701.42 | $5p\,^4F^\circ_{4\frac{1}{2}} - 8d\,^4G_{4\frac{1}{2}}$ |
| 2968.804 | 2 | 33673.77 | $5p\,^4F^\circ_{4\frac{1}{2}} - 8d\,^4G_{5\frac{1}{2}}$ |
| 2968.892 | 25 | 33672.77 | $5p\,^4F^\circ_{4\frac{1}{2}} - 8d\,^4F_{4\frac{1}{2}}$ |
| 2969.348 | 150 | 33667.60 | $4p\,^2D^\circ_{1\frac{1}{2}} - s^2\,^2F_{2\frac{1}{2}}$ |
| 2969.846 | 30 | 33661.95 | $5p\,^4F^\circ_{4\frac{1}{2}} - 8d\,^4H_{5\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II — Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 2970.651 | 1 | 33652.83 | |
| 2971.475 | 3 | 33643.50 | |
| 2972.457 | 10 | 33632.38 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 5s'\ ^2D_{2\frac{1}{2}}$ |
| 2973.004 | 15 | 33626.20 | $5p\ ^4F_{4\frac{1}{2}} - 8d\ ^4D_{3\frac{1}{2}}$ |
| 2974.655 | 3 | 33607.53 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 8d\ ^4G_{4\frac{1}{2}}$ |
| 2974.729 | 20 | 33606.70 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 8d\ ^4F_{4\frac{1}{2}}$ |
| 2975.710 | 10 | 33595.62 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 8d\ ^4H_{5\frac{1}{2}}$ |
| 2976.391 | 40 | 33587.93 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 8d\ ^4H_{6\frac{1}{2}}$ |
| 2978.695 | 2 | 33561.95 | |
| 2981.042 | 25 | 33535.53 | $5p\ ^4D^\circ_{3\frac{1}{2}} - 9s\ ^4F_{4\frac{1}{2}}$ |
| 2982.291 | 10 | 33521.49 | $4d\ ^2D_{2\frac{1}{2}} - 6f\ ^2G^\circ_{3\frac{1}{2}}$ |
| 2982.943 | 20 | 33514.16 | $5p\ ^2G^\circ_{4\frac{1}{2}} - 8d\ ^2H_{5\frac{1}{2}}$ |
| 2983.197 | 10 | 33511.31 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 8d\ ^4D_{2\frac{1}{2}}$ |
| 2983.544 | 10 | 33507.41 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 4d\ ^2P_{1\frac{1}{2}}$ |
| 2985.611 | 10 | 33484.21 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 8d\ ^4G_{4\frac{1}{2}}$ |
| 2986.135 | 1 | 33478.34 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 8d\ ^4F_{3\frac{1}{2}}$ |
| 2988.075 | 60 | 33456.60 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 8d\ ^4G_{5\frac{1}{2}}$ |
| 2988.166 | 2 | 33455.58 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 8d\ ^4F_{4\frac{1}{2}}$ |
| 2990.964 | 2 | 33424.29 | |
| 2991.071 | 20 | 33423.09 | $4d\ ^4D_{2\frac{1}{2}} - 4f'\ ^2P^\circ_{1\frac{1}{2}}$ |
| 2992.343 | 1 | 33408.89 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 8d\ ^4D_{3\frac{1}{2}}$ |
| 2996.008 | 5 | 33368.02 | $5p\ ^4F_{3\frac{1}{2}} - 8d\ ^4D_{2\frac{1}{2}}$ |
| 2998.054 | 5 | 33345.25 | |
| 2999.977 | 2 | 33323.87 | |
| 3000.337 | 2 | 33319.87 | |
| 3004.534 | 3 | 33273.33 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 8d\ ^4F_{3\frac{1}{2}}$ |
| 3005.082 | 3 | 33267.27 | |
| 3009.433 | 3 | 33219.17 | |
| 3013.567 | 5 | 33173.60 | $5p\ ^4G^\circ_{2\frac{1}{2}} - 9s\ ^4F_{1\frac{1}{2}}$ |
| 3013.713 | 5 | 33171.99 | |
| 3015.238 | 5 | 33155.22 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 9s\ ^4F_{3\frac{1}{2}}$ |
| 3015.947 | 20 | 33147.42 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 5s'\ ^2D_{1\frac{1}{2}}$ |
| 3016.996 | 20 | 33135.90 | $5p\ ^4D^\circ_{1\frac{1}{2}} - 9s\ ^4F_{2\frac{1}{2}}$ |
| | | | $5p\ ^4F_{3\frac{1}{2}} - 8d\ ^4G_{4\frac{1}{2}}$ |
| 3017.531 | 10 | 33130.03 | $5p\ ^4F_{3\frac{1}{2}} - 8d\ ^4F_{3\frac{1}{2}}$ |
| 3019.580 | 20 | 33107.55 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 9s\ ^4F_{4\frac{1}{2}}$ |
| 3020.902 | 10 | 33093.06 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^2F_{2\frac{1}{2}}$ |
| 3021.015 | 20 | 33091.82 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^2P_{0\frac{1}{2}}$ |
| 3021.415 | 3 | 33087.44 | $5p\ ^4F^\circ_{1\frac{1}{2}} - 9s\ ^4F_{1\frac{1}{2}}$ |
| 3022.407 | 10 | 33076.58 | $5p\ ^4G^\circ_{3\frac{1}{2}} - 9s\ ^4F_{2\frac{1}{2}}$ |
| 3025.054 | 2 | 33047.64 | $4p''\ ^4P^\circ_{0\frac{1}{2}} - 4d\ ^2P_{1\frac{1}{2}}$ |
| | | | $4d\ ^2F_{2\frac{1}{2}} - 6f\ ^4D^\circ_{2\frac{1}{2}}$ |
| 3025.635 | 30 | 33041.29 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 9s\ ^4F_{4\frac{1}{2}}$ |
| 3027.267 | 1 | 33023.48 | |
| 3027.383 | 50 | 33022.21 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 5s'\ ^2D_{2\frac{1}{2}}$ |
| 3029.030 | 2 | 33004.26 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^2G_{3\frac{1}{2}}$ |
| 3030.390 | 2 | 32989.45 | |
| 3031.735 | 20 | 32974.81 | $5p\ ^2G^\circ_{4\frac{1}{2}} - 9s\ ^2F_{3\frac{1}{2}}$ |
| 3032.458 | 5 | 32966.95 | $4s'\ ^2D_{2\frac{1}{2}} - 4p\ ^4F^\circ_{2\frac{1}{2}}$ |
| 3035.117 | 20 | 32938.07 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 9s\ ^4F_{3\frac{1}{2}}$ |
| 3039.521 | 10 | 32890.35 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 9s\ ^4F_{4\frac{1}{2}}$ |
| 3040.020 | 5 | 32884.95 | $4d\ ^2D_{1\frac{1}{2}} - 6f\ ^4G^\circ_{2\frac{1}{2}}$ |
| 3041.261 | 5 | 32871.53 | $5p\ ^2G^\circ_{3\frac{1}{2}} - 9s\ ^2F_{2\frac{1}{2}}$ |
| 3041.619 | 5 | 32867.66 | $4d\ ^2D_{1\frac{1}{2}} - 6f\ ^4F^\circ_{1\frac{1}{2}}$ |
| 3042.049 | 2 | 32863.02 | |
| 3042.915 | 3 | 32853.67 | $4d\ ^2D_{1\frac{1}{2}} - 6f\ ^4D^\circ_{0\frac{1}{2}}$ |
| 3047.009 | 2 | 32809.53 | |
| 3054.822 | 10 | 32725.62 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 9s\ ^2F_{3\frac{1}{2}}$ |
| 3056.985 | 8 | 32702.46 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 9s\ ^2F_{3\frac{1}{2}}$ |
| 3063.942 | 5 | 32628.21 | $4s'\ ^2D_{1\frac{1}{2}} - 4p\ ^4F^\circ_{1\frac{1}{2}}$ |
| 3066.237 | 8 | 32603.79 | $4d\ ^2D_{2\frac{1}{2}} - 6f\ ^2F^\circ_{3\frac{1}{2}}$ |
| 3067.558 | 15 | 32589.75 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 9s\ ^4F_{3\frac{1}{2}}$ |
| 3078.930 | 15 | 32469.38 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 4d\ ^4P_{1\frac{1}{2}}$ |
| 3084.578 | 4 | 32409.93 | $5p\ ^2F^\circ_{2\frac{1}{2}} - 9s\ ^2F_{2\frac{1}{2}}$ |
| 3087.069 | 75 | 32383.78 | $4s''\ ^4P_{2\frac{1}{2}} - 4p\ ^2D^\circ_{2\frac{1}{2}}$ |
| 3087.904 | 4 | 32375.03 | $4d\ ^2D_{2\frac{1}{2}} - 4f''\ ^2F^\circ_{3\frac{1}{2}}$ |
| 3109.196 | 8 | 32153.33 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 8d\ ^4D_{2\frac{1}{2}}$ |
| 3118.012 | 2 | 32062.42 | $4d\ ^4P_{1\frac{1}{2}} - 5f\ ^4G^\circ_{2\frac{1}{2}}$ |
| 3127.276 | 5 | 31967.44 | $s^2\ ^2P_{1\frac{1}{2}} - 5p\ ^2D^\circ_{2\frac{1}{2}}$ |
| 3137.363 | 2 | 31864.67 | $4p'\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^4D_{2\frac{1}{2}}$ |
| 3138.238 | 8 | 31855.78 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^4P_{0\frac{1}{2}}$ |
| 3138.877 | 8 | 31849.30 | $4d\ ^2D_{1\frac{1}{2}} - 4f''\ ^2D^\circ_{2\frac{1}{2}}$ |
| 3143.948 | 8 | 31797.93 | $4d\ ^2D_{1\frac{1}{2}} - 4f''\ ^4F^\circ_{2\frac{1}{2}}$ |
| 3148.207 | 4 | 31754.92 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^4D_{1\frac{1}{2}}$ |
| 3148.870 | 10 | 31748.23 | $4d\ ^4D_{3\frac{1}{2}} - 5f\ ^2G^\circ_{4\frac{1}{2}}$ |
| 3149.525 | 5 | 31741.63 | $4d\ ^4D_{3\frac{1}{2}} - 5f\ ^4G^\circ_{3\frac{1}{2}}$ |
| 3149.700 | 10 | 31739.86 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^2F_{3\frac{1}{2}}$ |
| 3167.084 | 20 | 31565.65 | $4d\ ^4D_{2\frac{1}{2}} - 5f\ ^2G^\circ_{3\frac{1}{2}}$ |
| 3179.620 | 20 | 31441.20 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 7d\ ^2F_{3\frac{1}{2}}$ |
| 3189.630 | 30 | 31342.54 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^2P_{1\frac{1}{2}}$ |
| 3192.582 | 4 | 31313.56 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 7d\ ^4H_{4\frac{1}{2}}$ |
| 3193.677 | 2 | 31302.82 | |
| 3194.183 | 10 | 31297.86 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 7d\ ^2F_{3\frac{1}{2}}$ |
| 3195.177 | 8 | 31288.13 | $4p''\ ^2D^\circ_{1\frac{1}{2}} - 4d\ ^2D_{1\frac{1}{2}}$ |
| 3195.294 | 5 | 31286.98 | $4s''\ ^4P_{1\frac{1}{2}} - 4p\ ^4F^\circ_{2\frac{1}{2}}$ |
| 3202.312 | 10 | 31218.42 | $4d\ ^4H_{5\frac{1}{2}} - 5f\ ^2\ I^\circ_{6\frac{1}{2}}$ |
| 3211.062 | 5 | 31133.35 | $5p\ ^2G^\circ_{3\frac{1}{2}} - 8d\ ^4F_{4\frac{1}{2}}$ |
| | | | $4d\ ^4P_{1\frac{1}{2}} - 5f\ ^2P^\circ_{1\frac{1}{2}}$ |
| 3213.172 | 3 | 31112.91 | $4p'\ ^2P^\circ_{1\frac{1}{2}} - 4d\ ^2P_{1\frac{1}{2}}$ |
| 3213.771 | 8 | 31107.11 | $4d\ ^4P_{1\frac{1}{2}} - 5f\ ^4P^\circ_{0\frac{1}{2}}$ |
| 3214.498 | 10 | 31100.07 | $4d\ ^4P_{0\frac{1}{2}} - 5f\ ^4F^\circ_{1\frac{1}{2}}$ |
| 3215.299 | 4 | 31092.33 | |
| 3222.336 | 10 | 31024.43 | $4d\ ^2P_{1\frac{1}{2}} - 5f\ ^4G^\circ_{2\frac{1}{2}}$ |
| 3229.634 | 40 | 30954.32 | $5p\ ^4D^\circ_{3\frac{1}{2}} - 7d\ ^4F_{4\frac{1}{2}}$ |
| 3230.237 | 2 | 30948.55 | |
| 3234.279 | 20 | 30909.87 | |
| 3236.743 | 150 | 30886.34 | $5p\ ^4D^\circ_{3\frac{1}{2}} - 7d\ ^4P_{2\frac{1}{2}}$ |
| 3237.932 | 5h | 30875.00 | $4d\ ^4F_{3\frac{1}{2}} - 5f\ ^2G^\circ_{4\frac{1}{2}}$ |
| 3238.017 | 100 | 30874.19 | $5p\ ^4D^\circ_{3\frac{1}{2}} - 7d\ ^4D_{3\frac{1}{2}}$ |
| 3243.894 | 10 | 30818.26 | |
| 3247.111 | 5 | 30787.72 | |
| 3248.703 | 10 | 30772.64 | $4d\ ^4G_{4\frac{1}{2}} - 5f\ ^2G^\circ_{4\frac{1}{2}}$ |
| 3249.746 | 15 | 30762.76 | $4d\ ^4G_{4\frac{1}{2}} - 5f\ ^2H^\circ_{5\frac{1}{2}}$ |
| 3249.836 | 20 | 30761.91 | |
| 3251.249 | 20 | 30748.54 | |
| 3251.966 | 30 | 30741.76 | $4d\ ^4G_{4\frac{1}{2}} - 5f\ ^4\ I^\circ_{5\frac{1}{2}}$ |
| 3252.639 | 5 | 30735.40 | $4d\ ^4F_{2\frac{1}{2}} - 5f\ ^2G^\circ_{3\frac{1}{2}}$ |
| 3259.778 | 5 | 30668.09 | $4d\ ^4D_{2\frac{1}{2}} - 5f\ ^2D^\circ_{2\frac{1}{2}}$ |
| 3259.947 | 30 | 30666.50 | $4d\ ^4D_{2\frac{1}{2}} - 5f\ ^2F^\circ_{3\frac{1}{2}}$ |
| 3260.246 | 10 | 30663.69 | |
| 3261.086 | 2 | 30655.79 | |
| 3261.753 | 40 | 30649.52 | $4d\ ^4D_{2\frac{1}{2}} - 5f\ ^4G^\circ_{3\frac{1}{2}}$ |
| 3262.481 | 1 | 30642.68 | $4d\ ^4D_{1\frac{1}{2}} - 5f\ ^2F^\circ_{2\frac{1}{2}}$ |
| 3262.615 | 15 | 30641.43 | $s^2\ ^2F_{3\frac{1}{2}} - 6p\ ^2G^\circ_{4\frac{1}{2}}$? |
| 3263.309 | 10 | 30634.91 | |
| 3264.364 | 100 | 30625.01 | $4d\ ^4D_{2\frac{1}{2}} - 5f\ ^4F^\circ_{2\frac{1}{2}}$ |
| 3264.980 | 20 | 30619.23 | $4d\ ^4D_{1\frac{1}{2}} - 5f\ ^4F^\circ_{1\frac{1}{2}}$ |
| 3265.173 | 8 | 30617.42 | $4d\ ^2F_{3\frac{1}{2}} - 5f\ ^2H^\circ_{4\frac{1}{2}}$ |
| 3265.306 | 20 | 30616.17 | $5p\ ^4G^\circ_{2\frac{1}{2}} - 7d\ ^4G_{2\frac{1}{2}}$ |
| 3265.466 | 30 | 30614.67 | $5p\ ^4D^\circ_{1\frac{1}{2}} - 7d\ ^4D_{1\frac{1}{2}}$ |
| | | | $4d\ ^4D_{2\frac{1}{2}} - 5f\ ^2P^\circ_{1\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 3265.730 | 100 | 30612.20 | $4d\ ^4D_{1\frac{1}{2}} - 5f\ ^4G^\circ_{2\frac{1}{2}}$ |
| | | | $5p\ ^4G^\circ_{2\frac{1}{2}} - 7d\ ^4H_{3\frac{1}{2}}$? |
| 3265.896 | 30 | 30610.64 | $5p\ ^4D^\circ_{1\frac{1}{2}} - 8s\ ^2F_{2\frac{1}{2}}$ |
| 3266.546 | 10 | 30604.55 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^4F_{3\frac{1}{2}}$ |
| 3267.329 | 40 | 30597.22 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 8s\ ^2F_{3\frac{1}{2}}$ |
| 3267.962 | 3h | 30591.29 | $4d\ ^2D_{1\frac{1}{2}} - 6f\ ^4S^\circ_{1\frac{1}{2}}$ |
| 3268.654 | 5 | 30584.82 | $4d\ ^4D_{1\frac{1}{2}} - 5f\ ^2D^\circ_{1\frac{1}{2}}$ |
| 3269.432 | 15 | 30577.54 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 7d\ ^4G_{4\frac{1}{2}}$ |
| 3269.925 | 20 | 30572.93 | $4d\ ^4D_{1\frac{1}{2}} - 5f\ ^4D^\circ_{0\frac{1}{2}}$ |
| 3270.317 | 200 | 30569.26 | $5p\ ^4G^\circ_{2\frac{1}{2}} - 7d\ ^4F_{1\frac{1}{2}}$ |
| 3271.199 | 5 | 30561.02 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 7d\ ^4F_{3\frac{1}{2}}$ |
| 3272.042 | 20 | 30553.15 | |
| 3272.223 | 5 | 30551.46 | $5p\ ^4G^\circ_{3\frac{1}{2}} - 8s\ ^2F_{2\frac{1}{2}}$ |
| 3273.389 | 2 | 30540.58 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^2F_{2\frac{1}{2}}$ |
| | | | $4d\ ^4G_{3\frac{1}{2}} - 5f\ ^2F^\circ_{2\frac{1}{2}}$ |
| 3273.519 | 4 | 30539.36 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^2P_{0\frac{1}{2}}$ |
| 3274.148 | 15 | 30533.50 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 7d\ ^4G^\circ_{5\frac{1}{2}}$ |
| 3274.310 | 10 | 30531.99 | $4d\ ^4G_{3\frac{1}{2}} - 5f\ ^2G^\circ_{3\frac{1}{2}}$ |
| 3274.517 | 100 | 30530.06 | $5p\ ^4F^\circ_{1\frac{1}{2}} - 7d\ ^4G_{2\frac{1}{2}}$ |
| 3274.917 | 100 | 30526.33 | $4s'\ ^2D_{2\frac{1}{2}} - 4p\ ^4D^\circ_{1\frac{1}{2}}$ |
| | | | $5p\ ^4F^\circ_{4\frac{1}{2}} - 7d\ ^4F_{4\frac{1}{2}}$ |
| 3275.982 | 150 | 30516.40 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 7d\ ^4H_{5\frac{1}{2}}$ |
| 3276.331 | 2 | 30513.15 | |
| 3276.747 | 2 | 30509.28 | $4p''\ ^4D^\circ_{0\frac{1}{2}} - 4d\ ^4F_{1\frac{1}{2}}$ |
| 3277.711 | 75 | 30500.31 | $4d\ ^4G_{3\frac{1}{2}} - 5f\ ^2H^\circ_{4\frac{1}{2}}$ |
| 3279.141 | 50 | 30487.01 | $5p\ ^4G^\circ_{3\frac{1}{2}} - 7d\ ^4G_{3\frac{1}{2}}$ |
| 3279.161 | 25 | 30486.82 | |
| 3279.556 | 2 | 30483.15 | $5p\ ^4F^\circ_{1\frac{1}{2}} - 7d\ ^4F_{1\frac{1}{2}}$ |
| 3280.085 | 2 | 30478.23 | $5p\ ^4G^\circ_{3\frac{1}{2}} - 7d\ ^2G_{4\frac{1}{2}}$ |
| 3280.407 | 50 | 30475.24 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 7d\ ^4D_{2\frac{1}{2}}$ |
| 3280.469 | 3 | 30474.67 | |
| 3280.661 | 30 | 30472.88 | $5s''\ ^4P_{2\frac{1}{2}} - 6p''\ ^4D^\circ_{3\frac{1}{2}}$ |
| 3281.269 | 20 | 30467.24 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 7d\ ^4G_{5\frac{1}{2}}$ |
| 3281.592 | 2 | 30464.24 | |
| 3281.824 | 10 | 30462.08 | $5p\ ^4D^\circ_{1\frac{1}{2}} - 7d\ ^4F_{2\frac{1}{2}}$ |
| 3281.938 | 100 | 30461.03 | $5p\ ^4G^\circ_{3\frac{1}{2}} - 7d\ ^4H_{4\frac{1}{2}}$ |
| 3282.044 | 20 | 30460.04 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 7d\ ^4F_{4\frac{1}{2}}$ |
| 3282.236 | 10 | 30458.26 | $4d\ ^4D_{2\frac{1}{2}} - \ ^4D^\circ_{2\frac{1}{2}}$? |
| 3283.113 | 75 | 30450.12 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 7d\ ^4H_{5\frac{1}{2}}$ |
| 3283.537 | 30 | 30446.19 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 7d\ ^4D_{3\frac{1}{2}}$ |
| 3284.660 | 300 | 30435.78 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 7d\ ^4H_{6\frac{1}{2}}$ |
| 3285.281 | 20 | 30430.03 | $4p'\ ^2F^\circ_{3\frac{1}{2}} - 4d\ ^4P_{2\frac{1}{2}}$ |
| 3288.050 | 3 | 30404.40 | |
| 3288.850 | 15 | 30397.01 | $5p\ ^2G^\circ_{4\frac{1}{2}} - 7d\ ^4G_{3\frac{1}{2}}$ |
| 3288.954 | 30 | 30396.05 | |
| 3289.043 | 50 | 30395.23 | $4d\ ^4D_{3\frac{1}{2}} - 5f\ ^4F^\circ_{4\frac{1}{2}}$ |
| 3289.781 | 100 | 30388.41 | $5p\ ^2G^\circ_{4\frac{1}{2}} - 7d\ ^2G_{4\frac{1}{2}}$ |
| 3289.976 | 200 | 30386.61 | $4d\ ^4D_{3\frac{1}{2}} - 5f\ ^4D^\circ_{2\frac{1}{2}}$ |
| | | | $4d\ ^4D_{3\frac{1}{2}} - 5f\ ^4G^\circ_{4\frac{1}{2}}$ |
| 3290.075 | 2 | 30385.69 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 7d\ ^4D_{1\frac{1}{2}}$ |
| 3290.138 | 25 | 30385.11 | $5s'\ ^2D^\circ_{2\frac{1}{2}} - 6p'\ ^2F^\circ_{3\frac{1}{2}}$ |
| 3290.506 | 10 | 30381.71 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 8s\ ^2F_{2\frac{1}{2}}$ |
| 3290.533 | 5 | 30381.46 | $4s''\ ^4P_{2\frac{1}{2}} - 4p\ ^4F^\circ_{3\frac{1}{2}}$ |
| 3290.679 | 3 | 30380.11 | $4s'\ ^2D_{1\frac{1}{2}} - 4p\ ^4D^\circ_{1\frac{1}{2}}$ |
| 3291.645 | 2 | 30371.20 | $5p\ ^2G^\circ_{4\frac{1}{2}} - 7d\ ^4H_{4\frac{1}{2}}$ |
| 3292.087 | 300 | 30367.12 | $5p\ ^2G^\circ_{4\frac{1}{2}} - 7d\ ^2H_{5\frac{1}{2}}$ |
| 3292.492 | 2 | 30363.39 | $5p\ ^4F^\circ_{1\frac{1}{2}} - 5d''\ ^4F_{1\frac{1}{2}}$ |
| 3292.575 | 30 | 30362.62 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 7d\ ^2D_{2\frac{1}{2}}$ |
| 3292.820 | 50 | 30360.36 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 7d\ ^4G_{4\frac{1}{2}}$ |

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 3292.872 | 400 | 30359.88 | $4d\ ^4D_{3\frac{1}{2}} - 5f\ ^4D^\circ_{3\frac{1}{2}}$ |
| 3293.345 | 20 | 30355.52 | $5p\ ^2G^\circ_{4\frac{1}{2}} - 7d\ ^2F_{3\frac{1}{2}}$ |
| 3294.612 | 2 | 30343.85 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 7d\ ^4F_{3\frac{1}{2}}$ |
| 3295.464 | 300 | 30336.00 | $4d\ ^4D_{3\frac{1}{2}} - 5f\ ^4P^\circ_{2\frac{1}{2}}$ |
| 3295.905 | 50 | 30331.95 | $5p\ ^2F_{3\frac{1}{2}} - 7d\ ^4D_{2\frac{1}{2}}$ |
| 3296.350 | 10 | 30327.85 | |
| 3297.150 | 15 | 30320.49 | $5s\ ^4F_{4\frac{1}{2}} - 6p\ ^4G^\circ_{5\frac{1}{2}}$ |
| 3297.501 | 150 | 30317.26 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 7d\ ^4G_{3\frac{1}{2}}$ |
| 3297.600 | 500 | 30316.35 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 7d\ ^4G_{5\frac{1}{2}}$ |
| | | | $5p\ ^2G^\circ_{3\frac{1}{2}} - 7d\ ^2G_{3\frac{1}{2}}$ |
| 3298.381 | 40 | 30309.18 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 7d\ ^4F_{4\frac{1}{2}}$ |
| 3298.478 | 2 | 30308.29 | |
| 3298.749 | 20 | 30305.80 | $4d\ ^4P_{2\frac{1}{2}} - 5f\ ^4F^\circ_{3\frac{1}{2}}$ |
| 3298.857 | 30 | 30304.80 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^4P_{1\frac{1}{2}}$ |
| 3299.561 | 1 | 30298.34 | |
| 3300.184 | 20 | 30292.62 | $4d\ ^4P_{2\frac{1}{2}} - 5f\ ^4D^\circ_{2\frac{1}{2}}$ |
| 3303.091 | 100 | 30265.96 | $4d\ ^4P_{2\frac{1}{2}} - 5f\ ^4D^\circ_{3\frac{1}{2}}$ |
| 3303.225 | 30 | 30264.73 | $4d\ ^4D_{0\frac{1}{2}} - 5f\ ^4F^\circ_{1\frac{1}{2}}$ |
| 3303.631 | 75 | 30261.01 | $4d\ ^4D_{2\frac{1}{2}} - 5f\ ^4P^\circ_{1\frac{1}{2}}$ |
| 3303.738 | 300 | 30260.03 | $5p\ ^2G^\circ_{3\frac{1}{2}} - 7d\ ^2H_{4\frac{1}{2}}$ |
| 3304.495 | 2 | 30253.10 | |
| 3305.709 | 400 | 30241.99 | $4d\ ^4P_{2\frac{1}{2}} - 5f\ ^4P^\circ_{2\frac{1}{2}}$ |
| 3306.672 | 30 | 30233.18 | $5p\ ^4F_{2\frac{1}{2}} - 7d\ ^4F_{2\frac{1}{2}}$ |
| 3307.126 | 25 | 30229.03 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 7d\ ^4D_{3\frac{1}{2}}$ |
| 3308.287 | 200 | 30218.43 | $4d\ ^4D_{0\frac{1}{2}} - 5f\ ^2D^\circ_{0\frac{1}{2}}$ |
| 3308.935 | 5 | 30212.51 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 8s\ ^2F_{2\frac{1}{2}}$ |
| 3311.033 | 2 | 30193.36 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 7d\ ^2D_{2\frac{1}{2}}$ |
| 3311.473 | 20 | 30189.35 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 8s\ ^2F_{2\frac{1}{2}}$ |
| 3311.614 | 10 | 30188.07 | |
| 3311.718 | 100 | 30187.12 | $4d\ ^4P_{0\frac{1}{2}} - 5f\ ^4D^\circ_{1\frac{1}{2}}$ |
| 3313.512 | 100 | 30170.78 | $4d\ ^4P_{2\frac{1}{2}} - 5f\ ^4S^\circ_{1\frac{1}{2}}$ |
| 3313.569 | 10 | 30170.26 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 7d\ ^2D_{2\frac{1}{2}}$ |
| 3313.942 | 40 | 30166.86 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 7d\ ^4P_{1\frac{1}{2}}$ |
| 3314.734 | 10 | 30159.65 | |
| 3315.929 | 40 | 30148.79 | $4d\ ^2P_{1\frac{1}{2}} - 5f\ ^2D^\circ_{2\frac{1}{2}}$ |
| 3316.507 | 40 | 30143.53 | |
| 3316.974 | 100 | 30139.29 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 7d\ ^2G_{4\frac{1}{2}}$ |
| 3317.019 | 30 | 30138.88 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 7d\ ^4F_{3\frac{1}{2}}$ |
| 3317.144 | 20 | 30137.74 | $4d\ ^4P_{0\frac{1}{2}} - 5f\ ^4P^\circ_{0\frac{1}{2}}$ |
| 3318.043 | 2 | 30129.58 | |
| 3318.197 | 3 | 30128.18 | |
| 3318.391 | 10 | 30126.42 | |
| 3319.272 | 40 | 30118.42 | $4d\ ^2P_{1\frac{1}{2}} - 5f\ ^4D^\circ_{1\frac{1}{2}}$ |
| 3320.604 | 50 | 30106.34 | $5p\ ^2F^\circ_{2\frac{1}{2}} - 7d\ ^2F_{3\frac{1}{2}}$ |
| 3320.688 | 10 | 30105.58 | $4d\ ^2P_{1\frac{1}{2}} - 5f\ ^4F^\circ_{2\frac{1}{2}}$ |
| 3321.665 | 30 | 30096.72 | $4p''\ ^4D^\circ_{0\frac{1}{2}} - 4d\ ^4D_{0\frac{1}{2}}$ |
| 3321.829 | 50 | 30095.24 | $4d\ ^2P_{1\frac{1}{2}} - 5f\ ^2P^\circ_{1\frac{1}{2}}$ |
| 3323.003 | 2 | 30084.61 | |
| 3323.164 | 25 | 30083.15 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 7d\ ^2F_{3\frac{1}{2}}$ |
| 3324.650 | 5 | 30069.70 | $5p\ ^2D^\circ_{1\frac{1}{2}} - 5d''\ ^2P_{0\frac{1}{2}}$? |
| 3324.720 | 75 | 30069.07 | $4d\ ^2P_{1\frac{1}{2}} - 5f\ ^4P^\circ_{0\frac{1}{2}}$ |
| 3325.292 | 20 | 30063.90 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 7d\ ^4F_{2\frac{1}{2}}$ |
| 3325.494 | 200 | 30062.07 | $5p\ ^4D^\circ_{3\frac{1}{2}} - 8s\ ^4F_{4\frac{1}{2}}$ |
| 3327.125 | 30 | 30047.34 | $4d\ ^4H_{6\frac{1}{2}} - 5f\ ^4G^\circ_{5\frac{1}{2}}$ |
| 3327.859 | 25 | 30040.71 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 7d\ ^4F_{2\frac{1}{2}}$ |
| 3327.943 | 25 | 30039.95 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d\ ^2D_{2\frac{1}{2}}$ |
| 3328.310 | 60 | 30036.64 | |
| 3331.034 | 150 | 30012.08 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 7d\ ^4G_{4\frac{1}{2}}$ |
| 3331.875 | 2000 | 30004.50 | $4d\ ^4H_{6\frac{1}{2}} - 5f\ ^4I^\circ_{7\frac{1}{2}}$ |
| 3332.868 | 150 | 29995.56 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 7d\ ^4F_{3\frac{1}{2}}$ |



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TABLE I. *Lines of* Ni II — Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 3333.703 | 20 | 29988.05 | |
| 3333.872 | 50 | 29986.53 | |
| 3335.316 | 2 | 29973.55 | |
| 3335.562 | 30 | 29971.34 | |
| 3335.639 | 400 | 29970.64 | $4d\,^4H_{3\frac{1}{2}} - 5f\,^4I^\circ_{4\frac{1}{2}}$ |
| 3336.770 | 40 | 29960.49 | $5p\,^4D^\circ_{0\frac{1}{2}} - 8s\,^4F_{1\frac{1}{2}}$ |
| 3337.108 | 2 | 29957.45 | $4p''\,^4D^\circ_{2\frac{1}{2}} - 4d\,^4G_{3\frac{1}{2}}$ |
| 3337.177 | 1 | 29956.83 | $4d\,^2D_{2\frac{1}{2}} - 4f'\,^2P^\circ_{1\frac{1}{2}}$ |
| 3338.092 | 500 | 29948.62 | $4d\,^4H_{3\frac{1}{2}} - 5f\,^2H^\circ_{4\frac{1}{2}}$ |
| 3338.344 | 3 | 29946.36 | $5s'\,^2D_{2\frac{1}{2}} - 4f''\,^4D^\circ_{3\frac{1}{2}}$ |
| 3340.376 | 5 | 29928.14 | |
| 3341.371 | 2 | 29919.23 | $5p\,^4F^\circ_{1\frac{1}{2}} - 5d''\,^4D_{2\frac{1}{2}}$? |
| 3342.640 | 5 | 29907.87 | |
| 3342.831 | 15 | 29906.17 | $4d\,^2H_{5\frac{1}{2}} - 5f\,^2G^\circ_{4\frac{1}{2}}$<br>$5s\,^2F_{3\frac{1}{2}} - 6p\,^2G^\circ_{4\frac{1}{2}}$ |
| 3343.352 | 2 | 29901.51 | |
| 3343.473 | 80 | 29900.42 | $4d\,^4H_{5\frac{1}{2}} - 5f\,^4G^\circ_{5\frac{1}{2}}$ |
| 3343.938 | 100 | 29896.27 | $4d\,^2H_{5\frac{1}{2}} - 5f\,^2H^\circ_{5\frac{1}{2}}$ |
| 3344.224 | 5 | 29893.71 | $4d\,^4H_{4\frac{1}{2}} - 5f\,^2F^\circ_{3\frac{1}{2}}$ |
| 3344.304 | 30 | 29892.99 | $4d\,^4H_{5\frac{1}{2}} - 5f\,^4F^\circ_{4\frac{1}{2}}$ |
| 3345.070 | 300 | 29886.15 | $4d\,^4H_{5\frac{1}{2}} - 5f\,^4H^\circ_{6\frac{1}{2}}$<br>$4d\,^2F_{2\frac{1}{2}} - 5f\,^2F^\circ_{2\frac{1}{2}}$ |
| 3345.385 | 10 | 29883.33 | $4d\,^4H_{4\frac{1}{2}} - 5f\,^2G^\circ_{4\frac{1}{2}}$ |
| 3345.930 | 400 | 29878.47 | $4d\,^2H_{5\frac{1}{2}} - 5f\,^2I^\circ_{6\frac{1}{2}}$ |
| 3346.023 | 200 | 29877.64 | $5p\,^2F^\circ_{2\frac{1}{2}} - 7d\,^2F_{2\frac{1}{2}}$<br>$4d\,^2F_{2\frac{1}{2}} - 5f\,^2G^\circ_{3\frac{1}{2}}$ |
| 3346.257 | 150 | 29875.55 | $4d\,^4F_{1\frac{1}{2}} - 5f\,^2F^\circ_{2\frac{1}{2}}$ |
| 3346.340 | 100 | 29874.81 | $4d\,^4H_{4\frac{1}{2}} - 5f\,^4H^\circ_{4\frac{1}{2}}$ |
| 3346.485 | 40 | 29873.51 | $4d\,^4H_{4\frac{1}{2}} - 5f\,^2H^\circ_{5\frac{1}{2}}$ |
| 3347.141 | 200 | 29867.66 | $4d\,^4H_{5\frac{1}{2}} - 5f\,^4H^\circ_{5\frac{1}{2}}$ |
| 3347.549 | 50 | 29864.02 | $4d\,^2P_{0\frac{1}{2}} - 5f\,^4F^\circ_{1\frac{1}{2}}$ |
| 3347.685 | 20 | 29862.80 | $4d\,^2F_{2\frac{1}{2}} - 5f\,^4F^\circ_{1\frac{1}{2}}$ |
| 3348.477 | 30 | 29855.74 | $4d\,^2F_{2\frac{1}{2}} - 5f\,^4G^\circ_{2\frac{1}{2}}$ |
| 3348.516 | 10 | 29855.39 | $4p''\,^4D^\circ_{2\frac{1}{2}} - 4d\,^4D_{1\frac{1}{2}}$ |
| 3348.609 | 40 | 29854.56 | $5p\,^2F^\circ_{2\frac{1}{2}} - 7d\,^2G_{3\frac{1}{2}}$ |
| 3348.842 | 500 | 29852.49 | $4d\,^4H_{4\frac{1}{2}} - 5f\,^4I^\circ_{5\frac{1}{2}}$ |
| 3349.235 | 500 | 29848.98 | $4d\,^4H_{5\frac{1}{2}} - 5f\,^4I^\circ_{6\frac{1}{2}}$ |
| 3349.523 | 1 | 29846.42 | |
| 3349.669 | 75 | 29845.12 | $4d\,^4F_{1\frac{1}{2}} - 5f\,^4G^\circ_{2\frac{1}{2}}$ |
| 3349.851 | 40 | 29843.50 | $4d\,^2D_{2\frac{1}{2}} - 4f'\,^2F^\circ_{3\frac{1}{2}}$ |
| 3350.410 | 20 | 29838.52 | $4s'\,^2D_{1\frac{1}{2}} - 4p\,^4D^\circ_{1\frac{1}{2}}$ |
| 3350.467 | 75 | 29838.01 | $4d\,^4F_{2\frac{1}{2}} - 5f\,^2D^\circ_{2\frac{1}{2}}$ |
| 3350.647 | 150 | 29836.41 | $4d\,^4F_{2\frac{1}{2}} - 5f\,^2F^\circ_{3\frac{1}{2}}$ |
| 3351.101 | 2 | 29832.36 | |
| 3351.404 | 100 | 29829.67 | $4d\,^2P_{0\frac{1}{2}} - 5f\,^2D^\circ_{1\frac{1}{2}}$ |
| 3352.562 | 200 | 29819.36 | $4d\,^4F_{2\frac{1}{2}} - 5f\,^4G^\circ_{3\frac{1}{2}}$ |
| 3352.741 | 20 | 29817.77 | $5p\,^2D^\circ_{1\frac{1}{2}} - 7d\,^2F_{2\frac{1}{2}}$ |
| 3352.813 | 10 | 29817.13 | $5p\,^2F^\circ_{2\frac{1}{2}} - 7d\,^4G_{2\frac{1}{2}}$ |
| 3353.260 | 100 | 29813.16 | $4d\,^4P_{1\frac{1}{2}} - 5f\,^4D^\circ_{2\frac{1}{2}}$<br>$5p\,^2D^\circ_{1\frac{1}{2}} - 7d\,^2P_{0\frac{1}{2}}$ |
| 3353.456 | 1 | 29811.41 | |
| 3353.874 | 25 | 29807.70 | $4d\,^4F_{2\frac{1}{2}} - 5f\,^4D^\circ_{1\frac{1}{2}}$ |
| 3354.085 | 40 | 29805.82 | $4d\,^4F_{1\frac{1}{2}} - 5f\,^4D^\circ_{0\frac{1}{2}}$ |
| 3355.315 | 30 | 29794.90 | $4d\,^4F_{2\frac{1}{2}} - 5f\,^4F^\circ_{2\frac{1}{2}}$ |
| 3356.525 | 25 | 29784.16 | $4p''\,^4D^\circ_{1\frac{1}{2}} - 4d\,^4D_{1\frac{1}{2}}$ |
| 3356.825 | 150 | 29781.50 | $4d\,^4P_{1\frac{1}{2}} - 5f\,^4P^\circ_{1\frac{1}{2}}$ |
| 3357.035 | 10 | 29779.63 | |
| 3357.850 | 5 | 29772.41 | |
| 3358.254 | 2 | 29768.82 | |
| 3358.368 | 1 | 29767.81 | $4d\,^2H_{4\frac{1}{2}} - 5f\,^2G^\circ_{3\frac{1}{2}}$ |
| 3358.400 | 25 | 29767.53 | $4d\,^4G_{2\frac{1}{2}} - 5f\,^2F^\circ_{2\frac{1}{2}}$? |
| 3358.676 | 600 | 29765.08 | $4d\,^2H_{4\frac{1}{2}} - 5f\,^2I^\circ_{5\frac{1}{2}}$ |
| 3358.975 | 2 | 29762.43 | $4d\,^4P_{1\frac{1}{2}} - 5f\,^4P^\circ_{2\frac{1}{2}}$ |
| 3359.218 | 10 | 29760.28 | $4p''\,^2P^\circ_{0\frac{1}{2}} - 4d\,^2D_{1\frac{1}{2}}$ |
| 3359.366 | 150 | 29758.97 | $4d\,^4P_{1\frac{1}{2}} - 5f\,^2S^\circ_{0\frac{1}{2}}$<br>$4d\,^2G_{2\frac{1}{2}} - 5f\,^2G^\circ_{3\frac{1}{2}}$ |
| 3359.463 | 40 | 29758.11 | $4d\,^2H_{4\frac{1}{2}} - 5f\,^4I^\circ_{4\frac{1}{2}}$ |
| 3359.566 | 10 | 29757.20 | $5p\,^2D^\circ_{1\frac{1}{2}} - 5d''\,^4P_{1\frac{1}{2}}$ |
| 3359.927 | 3 | 29754.00 | $4p''\,^4D^\circ_{2\frac{1}{2}} - 4d\,^4F_{2\frac{1}{2}}$ |
| 3360.189 | 30 | 29751.68 | $4d\,^2F_{3\frac{1}{2}} - 5f\,^2D^\circ_{2\frac{1}{2}}$ |
| 3360.372 | 300 | 29750.06 | $4d\,^2F_{3\frac{1}{2}} - 5f\,^2F^\circ_{3\frac{1}{2}}$ |
| 3361.825 | 100 | 29737.20 | $4d\,^4G_{5\frac{1}{2}} - 5f\,^4G^\circ_{5\frac{1}{2}}$ |
| 3361.858 | 200 | 29736.91 | $4d\,^4G_{2\frac{1}{2}} - 5f\,^4G^\circ_{2\frac{1}{2}}$ |
| 3361.944 | 30 | 29736.15 | $4d\,^2H_{4\frac{1}{2}} - 5f\,^2H^\circ_{4\frac{1}{2}}$ |
| 3362.292 | 40 | 29733.07 | $4d\,^2F_{3\frac{1}{2}} - 5f\,^4G^\circ_{3\frac{1}{2}}$ |
| 3362.519 | 100 | 29731.07 | $4d\,^2F_{3\frac{1}{2}} - 5f\,^4H^\circ_{4\frac{1}{2}}$ |
| 3362.674 | 10 | 29729.70 | $4d\,^4G_{5\frac{1}{2}} - 5f\,^4F^\circ_{4\frac{1}{2}}$ |
| 3363.451 | 500 | 29722.83 | $4d\,^4G_{5\frac{1}{2}} - 5f\,^4H^\circ_{6\frac{1}{2}}$ |
| 3363.644 | 30 | 29721.12 | $4d\,^4G_{5\frac{1}{2}} - 5f\,^4G^\circ_{4\frac{1}{2}}$ |
| 3364.324 | 400 | 29715.12 | $4d\,^4F_{4\frac{1}{2}} - 5f\,^4G^\circ_{5\frac{1}{2}}$ |
| 3364.445 | 10 | 29714.05 | |
| 3364.660 | 20 | 29712.15 | $4d\,^4F_{4\frac{1}{2}} - 5f\,^4F^\circ_{3\frac{1}{2}}$ |
| 3365.070 | 30 | 29708.53 | $4d\,^2F_{3\frac{1}{2}} - 5f\,^4F^\circ_{2\frac{1}{2}}$ |
| 3365.166 | 300 | 29707.68 | $4d\,^4F_{4\frac{1}{2}} - 5f\,^4F^\circ_{4\frac{1}{2}}$ |
| 3365.329 | 20 | 29706.24 | $4d\,^4D_{1\frac{1}{2}} - 5f\,^4D^\circ_{1\frac{1}{2}}$ |
| 3365.552 | 30 | 29704.27 | $4d\,^4G_{5\frac{1}{2}} - 5f\,^4H^\circ_{5\frac{1}{2}}$ |
| 3366.035 | 100 | 29700.01 | $5p\,^4G^\circ_{2\frac{1}{2}} - 8s\,^4F_{1\frac{1}{2}}$ |
| 3367.025 | 8 | 29691.28 | $4d\,^4P_{1\frac{1}{2}} - 5f\,^4S^\circ_{1\frac{1}{2}}$ |
| 3367.667 | 200 | 29685.62 | $4d\,^4G_{5\frac{1}{2}} - 5f\,^4I^\circ_{6\frac{1}{2}}$ |
| 3367.956 | 20 | 29683.07 | $4d\,^4D_{1\frac{1}{2}} - 5f\,^2P^\circ_{1\frac{1}{2}}$ |
| 3368.041 | 50 | 29682.32 | $4d\,^4F_{4\frac{1}{2}} - 5f\,^4H^\circ_{5\frac{1}{2}}$ |
| 3368.662 | 75 | 29676.85 | $5p\,^4D^\circ_{1\frac{1}{2}} - 8s\,^4F_{2\frac{1}{2}}$ |
| 3369.178 | 75 | 29672.31 | $4d\,^4F_{4\frac{1}{2}} - 5f\,^4D^\circ_{3\frac{1}{2}}$ |
| 3370.274 | 30 | 29662.66 | |
| 3371.284 | 10 | 29653.77 | $5p\,^4F^\circ_{4\frac{1}{2}} - 5d'\,^2F_{3\frac{1}{2}}$ |
| 3373.527 | 200 | 29634.05 | $5p\,^4F^\circ_{4\frac{1}{2}} - 8s\,^4F_{4\frac{1}{2}}$ |
| 3373.666 | 5 | 29632.83 | $4d\,^4G_{3\frac{1}{2}} - 5f\,^2F^\circ_{3\frac{1}{2}}$ |
| 3373.978 | 30 | 29630.09 | $4s'\,^2D_{2\frac{1}{2}} - 4p\,^4D^\circ_{2\frac{1}{2}}$ |
| 3374.837 | 40 | 29622.55 | $4d\,^4G_{3\frac{1}{2}} - 5f\,^4G^\circ_{4\frac{1}{2}}$ |
| 3375.395 | 150 | 29617.66 | $5p\,^4G^\circ_{3\frac{1}{2}} - 8s\,^4F_{2\frac{1}{2}}$ |
| 3375.596 | 75 | 29615.89 | $4d\,^4G_{3\frac{1}{2}} - 5f\,^4G^\circ_{3\frac{1}{2}}$ |
| 3375.817 | 400 | 29613.95 | $5p\,^4F^\circ_{1\frac{1}{2}} - 8s\,^4F_{1\frac{1}{2}}$<br>$4d\,^4G_{3\frac{1}{2}} - 5f\,^4H^\circ_{4\frac{1}{2}}$ |
| 3376.655 | 10 | 29606.60 | $4d\,^2G_{4\frac{1}{2}} - 5f\,^2F^\circ_{3\frac{1}{2}}$ |
| 3377.385 | 2 | 29600.21 | |
| 3377.579 | 2 | 29598.51 | |
| 3377.838 | 200 | 29596.24 | $4d\,^2G_{4\frac{1}{2}} - 5f\,^2G^\circ_{4\frac{1}{2}}$ |
| 3378.385 | 20 | 29591.44 | $4d\,^4G_{3\frac{1}{2}} - 5f\,^4F^\circ_{2\frac{1}{2}}$ |
| 3378.481 | 3 | 29590.60 | $5p\,^2D^\circ_{1\frac{1}{2}} - 5d''\,^4F_{1\frac{1}{2}}$ |
| 3378.594 | 20 | 29589.61 | $4d\,^2G_{4\frac{1}{2}} - 5f\,^4G^\circ_{3\frac{1}{2}}$ |
| 3378.826 | 5h | 29587.58 | $4d\,^2G_{4\frac{1}{2}} - 5f\,^4H^\circ_{4\frac{1}{2}}$ |
| 3378.966 | 500 | 29586.36 | $4d\,^2G_{4\frac{1}{2}} - 5f\,^2H^\circ_{5\frac{1}{2}}$ |
| 3381.077 | 150 | 29567.88 | $5p\,^4G^\circ_{5\frac{1}{2}} - 8s\,^4F_{4\frac{1}{2}}$ |
| 3381.362 | 10 | 29565.39 | $4d\,^1G_{4\frac{1}{2}} - 5f\,^4I^\circ_{5\frac{1}{2}}$ |
| 3381.629 | 1 | 29563.06 | |
| 3383.154 | 5 | 29549.73 | $5p\,^4D^\circ_{2\frac{1}{2}} - 5d'\,^2D_{2\frac{1}{2}}$ |
| 3383.611 | 2 | 29545.74 | |
| 3385.815 | 400 | 29526.51 | $4d\,^4F_{3\frac{1}{2}} - 5f\,^4F^\circ_{3\frac{1}{2}}$ |
| 3386.332 | 400 | 29522.00 | $4d\,^4F_{3\frac{1}{2}} - 5f\,^4F^\circ_{4\frac{1}{2}}$ |
| 3387.323 | 200 | 29513.36 | $4d\,^4F_{3\frac{1}{2}} - 5f\,^4D^\circ_{2\frac{1}{2}}$<br>$4d\,^4F_{3\frac{1}{2}} - 5f\,^4G^\circ_{4\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 3387.524 | 200 | 29511.61 | $5p\ ^2G^\circ_{4\frac{1}{2}} - 8s\ ^2F_{3\frac{1}{2}}$ |
| 3388.743 | 5 | 29501.00 | |
| 3390.164 | 3 | 29488.63 | |
| 3393.284 | 25h | 29461.52 | |
| 3394.845 | 150 | 29447.97 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 8s\ ^4F_{2\frac{1}{2}}$ |
| 3395.388 | 10 | 29443.26 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 4d\ ^2P_{1\frac{1}{2}}$ |
| 3396.645 | 2 | 29432.37 | |
| 3396.920 | 30 | 29429.99 | $5p\ ^2G^\circ_{3\frac{1}{2}} - 8s\ ^2F_{2\frac{1}{2}}$ |
| 3397.247 | 2 | 29427.15 | $4d\ ^4G_{4\frac{1}{2}} - 5f\ ^4G^\circ_{5\frac{1}{2}}$ |
| 3397.590 | 30 | 29424.18 | $4d\ ^4G_{4\frac{1}{2}} - 5f\ ^4F^\circ_{3\frac{1}{2}}$ |
| 3397.810 | 5 | 29422.28 | $4s''\ ^2P_{1\frac{1}{2}} - 4p\ ^2F^\circ_{2\frac{1}{2}}$ |
| 3398.111 | 40 | 29419.67 | $4d\ ^4G_{4\frac{1}{2}} - 5f\ ^4F^\circ_{4\frac{1}{2}}$ |
| 3398.430 | 100 | 29416.91 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 8s\ ^4F_{4\frac{1}{2}}$ |
| 3399.107 | 400 | 29411.05 | $4d\ ^4G_{4\frac{1}{2}} - 5f\ ^4G^\circ_{4\frac{1}{2}}$ |
| 3399.644 | 2 | 29406.41 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 5d'\ ^2D_{2\frac{1}{2}}$ |
| 3401.046 | 500 | 29394.28 | $4d\ ^4G_{4\frac{1}{2}} - 5f\ ^4H^\circ_{5\frac{1}{2}}$ |
| 3401.765 | 20 | 29388.07 | $4s''\ ^4P_{1\frac{1}{2}} - 4p\ ^4D^\circ_{0\frac{1}{2}}$ |
| 3402.680 | 2 | 29380.17 | $4p''\ ^2S^\circ_{0\frac{1}{2}} - 4d\ ^2D_{1\frac{1}{2}}$ |
| 3403.276 | 300 | 29375.02 | $4d\ ^2G_{3\frac{1}{2}} - 5f\ ^4I^\circ_{4\frac{1}{2}}$ |
| 3403.620 | 2 | 29372.06 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^2P_{1\frac{1}{2}}$ |
| 3404.682 | 5 | 29362.89 | $4d\ ^2G_{3\frac{1}{2}} - 5f\ ^4G^\circ_{2\frac{1}{2}}$ |
| 3405.826 | 200 | 29353.03 | $4d\ ^2G_{3\frac{1}{2}} - 5f\ ^2H^\circ_{4\frac{1}{2}}$ |
| 3407.297 | 100 | 29340.36 | $4s''\ ^4P_{0\frac{1}{2}} - 4p\ ^4D^\circ_{0\frac{1}{2}}$ |
| 3411.098 | 50 | 29307.67 | $4d\ ^4D_{2\frac{1}{2}} - 5f\ ^4F^\circ_{3\frac{1}{2}}$ |
| 3411.230 | 40 | 29306.53 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 8s\ ^4F_{3\frac{1}{2}}$ |
| 3411.597 | 20 | 29303.38 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^4P_{0\frac{1}{2}}$ |
| 3412.631 | 75 | 29294.50 | $4d\ ^4D_{2\frac{1}{2}} - 5f\ ^4D^\circ_{2\frac{1}{2}}$ |
| 3415.685 | 5 | 29268.31 | |
| 3415.740 | 10 | 29267.84 | $4d\ ^4D_{2\frac{1}{2}} - 5f\ ^4D^\circ_{3\frac{1}{2}}$ |
| 3416.375 | 60 | 29262.40 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 8s\ ^2F_{3\frac{1}{2}}$ |
| 3418.551 | 10 | 29243.77 | $4d\ ^4D_{2\frac{1}{2}} - 5f\ ^4F^\circ_{2\frac{1}{2}}$ |
| 3419.085 | 150 | 29239.21 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 8s\ ^2F_{3\frac{1}{2}}$ |
| 3419.961 | 10 | 29231.72 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 5d'\ ^2F_{3\frac{1}{2}}$ |
| 3420.456 | 3 | 29227.49 | |
| 3425.838 | 20 | 29181.57 | |
| 3426.888 | 10 | 29172.63 | $4d\ ^4D_{2\frac{1}{2}} - 5f\ ^4S^\circ_{1\frac{1}{2}}$ |
| 3428.003 | 50 | 29163.14 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 8s\ ^4F_{3\frac{1}{2}}$ |
| 3429.266 | 2 | 29152.40 | |
| 3432.034 | 5 | 29128.89 | |
| 3432.784 | 5 | 29122.53 | |
| 3435.086 | 5 | 29103.01 | $5s\ ^4F_{4\frac{1}{2}} - 5p''\ ^4D^\circ_{3\frac{1}{2}}$ |
| 3435.586 | 5 | 29098.77 | |
| 3436.817 | 40 | 29088.35 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 5d'\ ^2F_{3\frac{1}{2}}$ |
| 3439.843 | 15 | 29062.76 | |
| 3439.900 | 20 | 29062.28 | $4d\ ^4H_{3\frac{1}{2}} - 5f\ ^4H^\circ_{4\frac{1}{2}}$ |
| 3443.979 | 15 | 29027.86 | |
| 3449.642 | 5 | 28980.21 | $4d\ ^2F_{2\frac{1}{2}} - 5f\ ^2D^\circ_{2\frac{1}{2}}$ |
| 3449.837 | 20 | 28978.57 | $4d\ ^2F_{2\frac{1}{2}} - 5f\ ^2F^\circ_{3\frac{1}{2}}$ |
| 3450.917 | 20 | 28969.50 | $4d\ ^4F_{1\frac{1}{2}} - 5f\ ^2D^\circ_{2\frac{1}{2}}$ |
| 3451.055 | 40 | 28968.35 | $5p\ ^2F^\circ_{2\frac{1}{2}} - 8s\ ^2F_{2\frac{1}{2}}$ |
| 3451.861 | 30 | 28961.58 | $4d\ ^2F_{2\frac{1}{2}} - 5f\ ^4G^\circ_{3\frac{1}{2}}$ |
| 3453.331 | 15h | 28949.25 | $5p\ ^2F^\circ_{2\frac{1}{2}} - 7d\ ^2D_{2\frac{1}{2}}$ |
| 3454.157 | 75 | 28942.33 | $4s'\ ^2D_{1\frac{1}{2}} - 4p\ ^4D^\circ_{2\frac{1}{2}}$ |
| 3454.531 | 15 | 28939.20 | $4d\ ^4F_{1\frac{1}{2}} - 5f\ ^4D^\circ_{1\frac{1}{2}}$ |
| 3454.783 | 40 | 28937.09 | $4d\ ^2F_{2\frac{1}{2}} - 5f\ ^4F^\circ_{2\frac{1}{2}}$ |
| 3456.025 | 15h | 28926.69 | $4d\ ^2F_{2\frac{1}{2}} - 5f\ ^2P^\circ_{1\frac{1}{2}}$ |
| 3456.356 | 25 | 28923.92 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 4d\ ^4D_{2\frac{1}{2}}$ |
| 3456.493 | 3 | 28922.77 | |
| 3456.921 | 5 | 28919.19 | |
| 3457.323 | 15h | 28915.83 | $4d\ ^4F_{1\frac{1}{2}} - \overline{5f\ ^2P^\circ_{1\frac{1}{2}}}$? |
| 3460.497 | 30h | 28889.31 | $5p\ ^2D^\circ_{1\frac{1}{2}} - 7d\ ^2D_{2\frac{1}{2}}$ |
| 3465.641 | 200 | 28846.43 | $4s''\ ^4P_{1\frac{1}{2}} - 4p\ ^4D^\circ_{1\frac{1}{2}}$ |
| 3467.921 | 10 | 28827.47 | $4d\ ^2H_{4\frac{1}{2}} - 6f\ ^4\ I^\circ_{5\frac{1}{2}}$ |
| 3468.752 | 10 | 28820.56 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 7d\ ^2G_{4\frac{1}{2}}$ |
| 3470.161 | 20 | 28808.86 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 7d\ ^4P_{1\frac{1}{2}}$ |
| 3470.738 | 10 | 28804.07 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 7d\ ^4F_{3\frac{1}{2}}$ |
| 3471.385 | 150 | 28798.70 | $4s''\ ^4P^\circ_{0\frac{1}{2}} - 4p\ ^4D_{1\frac{1}{2}}$ |
| 3473.497 | 5 | 28781.19 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 4d\ ^4D_{2\frac{1}{2}}$ |
| 3473.528 | 10 | 28780.93 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 7d\ ^4F_{3\frac{1}{2}}$ |
| 3474.231 | 5 | 28775.11 | $4d\ ^2P_{1\frac{1}{2}} - 5f\ ^4D^\circ_{2\frac{1}{2}}$ |
| 3474.768 | 3 | 28770.66 | |
| 3478.019 | 10 | 28743.77 | |
| 3478.290 | 20 | 28741.53 | |
| 3480.783 | 5 | 28720.95 | $4d\ ^2P_{1\frac{1}{2}} - 5f\ ^2S^\circ_{0\frac{1}{2}}$ |
| 3483.519 | 20 | 28698.39 | |
| 3484.215 | 15 | 28692.66 | |
| 3491.216 | 10h | 28635.12 | |
| 3491.404 | 3h | 28633.58 | |
| 3493.859 | 20 | 28613.46 | |
| 3495.715 | 3 | 28598.27 | $4s''\ ^4P_{2\frac{1}{2}} - 4p\ ^4D^\circ_{1\frac{1}{2}}$ |
| 3498.183 | 1 | 28578.09 | |
| 3504.039 | 1 | 28530.33 | $4d\ ^4H_{4\frac{1}{2}} - 5f\ ^4F^\circ_{4\frac{1}{2}}$ |
| 3506.654 | 5 | 28509.06 | $4d\ ^2H_{5\frac{1}{2}} - 5f\ ^4I^\circ_{6\frac{1}{2}}$ |
| 3507.154 | 10 | 28504.99 | $4d\ ^4H_{4\frac{1}{2}} - 5f\ ^4H^\circ_{5\frac{1}{2}}$ |
| 3511.875 | 20 | 28466.68 | $4d\ ^2G_{3\frac{1}{2}} - 5f\ ^4H^\circ_{4\frac{1}{2}}$ |
| 3512.164 | 20 | 28464.33 | $4d\ ^4F_{2\frac{1}{2}} - 5f\ ^4D^\circ_{2\frac{1}{2}}$ |
| 3513.486 | 10 | 28453.62 | |
| 3513.976 | 200 | 28449.66 | $4s'\ ^2D_{2\frac{1}{2}} - 4p\ ^4D^\circ_{3\frac{1}{2}}$ |
| 3516.073 | 5 | 28432.69 | $4d\ ^4F_{2\frac{1}{2}} - 5f\ ^4P^\circ_{1\frac{1}{2}}$ |
| 3516.612 | 3 | 28428.33 | |
| 3519.462 | 20 | 28405.31 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 4d\ ^4P_{1\frac{1}{2}}$ |
| 3520.460 | 2 | 28397.26 | |
| 3520.908 | 5 | 28393.65 | |
| 3521.220 | 2 | 28391.13 | $4d\ ^2F_{3\frac{1}{2}} - 5f\ ^4F^\circ_{3\frac{1}{2}}$ |
| 3522.845 | 2 | 28378.03 | $4d\ ^2F_{3\frac{1}{2}} - 5f\ ^4D^\circ_{2\frac{1}{2}}$<br>$4d\ ^2F_{3\frac{1}{2}} - 5f\ ^4G^\circ_{4\frac{1}{2}}$ |
| 3526.416 | 10 | 28349.30 | $4s''\ ^2P_{1\frac{1}{2}} - 4p\ ^2D^\circ_{2\frac{1}{2}}$ |
| 3528.385 | 3 | 28333.48 | |
| 3537.439 | 2 | 28260.96 | $4d\ ^4G_{3\frac{1}{2}} - 5f\ ^4G^\circ_{4\frac{1}{2}}$ |
| 3539.657 | 2 | 28243.25 | $4d\ ^2G_{4\frac{1}{2}} - 5f\ ^4F^\circ_{4\frac{1}{2}}$ |
| 3540.790 | 0 | 28234.22 | $4d\ ^4G_{3\frac{1}{2}} - 5f\ ^4D^\circ_{3\frac{1}{2}}$ |
| 3542.840 | 20 | 28217.88 | $4d\ ^2G_{4\frac{1}{2}} - 5f\ ^4H^\circ_{5\frac{1}{2}}$ |
| 3549.880 | 0 | 28161.92 | $5s'\ ^2D_{1\frac{1}{2}} - 6f\ ^4D^\circ_{2\frac{1}{2}}$ |
| 3556.689 | 10 | 28108.01 | $4d\ ^2D_{2\frac{1}{2}} - 5f\ ^2F^\circ_{2\frac{1}{2}}$ |
| 3557.776 | 40 | 28099.42 | $4d\ ^2D_{2\frac{1}{2}} - 5f\ ^2G^\circ_{3\frac{1}{2}}$ |
| 3559.275 | 2 | 28087.59 | |
| 3559.655 | 2 | 28084.59 | $4d\ ^2D_{2\frac{1}{2}} - 5f\ ^4F^\circ_{1\frac{1}{2}}$ |
| 3560.542 | 10 | 28077.59 | $4d\ ^2D_{2\frac{1}{2}} - 5f\ ^4G^\circ_{2\frac{1}{2}}$ |
| 3560.845 | 15 | 28075.20 | $5s'\ ^2D_{1\frac{1}{2}} - w\ ^2F^\circ_{2\frac{1}{2}}$ |
| 3564.780 | 3 | 28044.21 | |
| 3573.640 | 10 | 27974.69 | $5p\ ^2D^\circ_{1\frac{1}{2}} - 8s\ ^4F_{2\frac{1}{2}}$ |
| 3574.017 | 5 | 27971.74 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 8s\ ^4F_{3\frac{1}{2}}$ |
| 3576.765 | 150 | 27950.25 | $4s''\ ^4P_{1\frac{1}{2}} - 4p\ ^4D^\circ_{2\frac{1}{2}}$ |
| 3576.979 | 20 | 27948.57 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 8s\ ^4F_{3\frac{1}{2}}$ |
| 3583.298 | 5 | 27899.29 | |
| 3583.605 | 1 | 27896.90 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 5d'\ ^2F_{3\frac{1}{2}}$ |
| 3585.905 | 2 | 27879.01 | |
| 3591.986 | 1 | 27831.81 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 4d\ ^4D_{3\frac{1}{2}}$ |
| 3598.282 | 30 | 27783.11 | $4p''\ ^4D^\circ_{3\frac{1}{2}} - 4d\ ^4P_{2\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 3608.811 | 30 | 27702.06 | $4s''\ ^4P_{2\frac{1}{2}} - 4p\ ^4D^\circ_{2\frac{1}{2}}$ |
| 3608.998 | 20 | 27700.62 | |
| 3621.296 | 10 | 27606.55 | $4d\ ^2F_{2\frac{1}{2}} - 5f\ ^4D^\circ_{2\frac{1}{2}}$ |
| 3628.834 | 15 | 27549.21 | |
| 3630.638 | 10 | 27535.52 | |
| 3633.503 | 3 | 27513.81 | |
| 3639.287 | 20 | 27470.08 | $4d\ ^2D_{1\frac{1}{2}} - 5f\ ^2F^\circ_{2\frac{1}{2}}$ |
| 3643.326 | 20 | 27439.63 | $4d\ ^2D_{1\frac{1}{2}} - 5f\ ^4G^\circ_{2\frac{1}{2}}$ |
| 3646.968 | 5 | 27412.23 | $4d\ ^2D_{1\frac{1}{2}} - 5f\ ^2D^\circ_{1\frac{1}{2}}$ |
| 3648.552 | 3 | 27400.33 | $4d\ ^2D_{1\frac{1}{2}} - 5f\ ^4D^\circ_{0\frac{1}{2}}$ |
| 3657.812 | 3 | 27330.96 | |
| 3664.983 | 10 | 27277.49 | |
| 3665.185 | 20 | 27275.98 | |
| 3665.432 | 10 | 27274.15 | |
| 3666.000 | 20 | 27269.92 | $4p''\ ^2D^\circ_{2\frac{1}{2}} - 4d\ ^4P_{1\frac{1}{2}}$ |
| 3666.047 | 20 | 27269.57 | |
| 3666.522 | 3h | 27266.04 | |
| 3667.760 | 20 | 27256.83 | |
| 3669.883 | 10 | 27241.07 | |
| 3672.795 | 5 | 27219.47 | |
| 3675.165 | 15 | 27201.92 | $4d\ ^2D_{2\frac{1}{2}} - 5f\ ^2D^\circ_{2\frac{1}{2}}$ |
| 3675.389 | 30 | 27200.26 | $4d\ ^2D_{2\frac{1}{2}} - 5f\ ^2F^\circ_{3\frac{1}{2}}$ |
| 3676.524 | 5 | 27191.86 | |
| 3678.245 | 20 | 27179.14 | |
| 3678.857 | 30 | 27174.62 | |
| 3680.570 | 3 | 27161.97 | $5s'\ ^2D_{2\frac{1}{2}} - w\ ^2F^\circ_{3\frac{1}{2}}$ |
| 3680.999 | 3 | 27158.81 | $4d\ ^2D_{2\frac{1}{2}} - 5f\ ^4F^\circ_{2\frac{1}{2}}$ |
| 3681.309 | 5 | 27156.52 | |
| 3682.192 | 30 | 27150.01 | |
| 3682.408 | 3 | 27148.41 | $4d\ ^2D_{2\frac{1}{2}} - 5f\ ^2F^\circ_{1\frac{1}{2}}$ |
| 3684.457 | 30 | 27133.32 | $5s\ ^2F_{2\frac{1}{2}} - x\ ^2G^\circ_{3\frac{1}{2}}$ |
| 3687.495 | 30 | 27110.96 | |
| 3689.312 | 20 | 27097.61 | |
| 3689.892 | 2 | 27093.35 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d\ ^2P_{1\frac{1}{2}}$? |
| 3690.980 | 20 | 27085.37 | |
| 3692.542 | 3 | 27073.91 | |
| 3694.334 | 10 | 27060.78 | |
| 3694.919 | 5 | 27056.49 | |
| 3695.075 | 1 | 27055.35 | |
| 3696.999 | 3 | 27041.27 | |
| 3699.276 | 2 | 27024.63 | $4p''\ ^2P^\circ_{1\frac{1}{2}} - 4d\ ^4P_{1\frac{1}{2}}$ |
| 3699.942 | 2 | 27019.76 | |
| 3700.677 | 20 | 27014.40 | $5s''\ ^4P_{2\frac{1}{2}} - w\ ^2P^\circ_{1\frac{1}{2}}$ |
| 3707.804 | 10 | 26962.47 | |
| 3708.534 | 3 | 26957.16 | |
| 3723.689 | 5 | 26847.45 | |
| 3735.406 | 2 | 26763.24 | $5s\ ^4F_{4\frac{1}{2}} - 5p'\ ^2F^\circ_{3\frac{1}{2}}$ |
| 3753.047 | 2 | 26637.45 | |
| 3761.872 | 20 | 26574.96 | |
| 3763.424 | 10 | 26564.00 | $4d\ ^2D_{1\frac{1}{2}} - 5f\ ^2D^\circ_{2\frac{1}{2}}$ |
| 3767.725 | 10 | 26533.68 | $4d\ ^2D_{1\frac{1}{2}} - 5f\ ^4D^\circ_{1\frac{1}{2}}$ |
| 3768.424 | 5 | 26528.75 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^2D_{2\frac{1}{2}}$ |
| 3793.061 | 5 | 26356.45 | $5p\ ^4D^\circ_{1\frac{1}{2}} - 6d\ ^2F_{2\frac{1}{2}}$ |
| 3806.701 | 20 | 26262.01 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^2F_{3\frac{1}{2}}$ |
| 3809.080 | 10h | 26245.61 | |
| 3811.208 | 3 | 26230.95 | $5p\ ^4D^\circ_{1\frac{1}{2}} - 6d\ ^4G_{2\frac{1}{2}}$ |
| 3811.737 | 5 | 26227.31 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^4F_{2\frac{1}{2}}$ |
| 3812.692 | 3 | 26220.75 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - s^2\ ^2F_{3\frac{1}{2}}$ |
| 3813.382 | 10 | 26216.00 | $5p\ ^4D^\circ_{1\frac{1}{2}} - 6d\ ^2P_{0\frac{1}{2}}$ |
| 3817.437 | 20 | 26188.15 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^2P_{1\frac{1}{2}}$ |
| 3817.532 | 3 | 26187.50 | $5p\ ^4G^\circ_{3\frac{1}{2}} - 6d\ ^2H_{4\frac{1}{2}}$ |
| 3822.304 | 20 | 26154.81 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 6d\ ^2G_{4\frac{1}{2}}$ |
| 3826.310 | 5 | 26127.43 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 6d\ ^2F_{2\frac{1}{2}}$ |
| 3827.586 | 20 | 26118.72 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 6d\ ^2F_{3\frac{1}{2}}$ |
| 3828.719 | 3 | 26110.99 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 6d\ ^4H_4$ |
| 3832.982 | 5 | 26081.95 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 6d\ ^2G_{3\frac{1}{2}}$ |
| 3849.551 | 30 | 25969.69 | $4s'''\ ^2G_{3\frac{1}{2}} - 4p\ ^2F^\circ_{2\frac{1}{2}}$ |
| 3857.576 | 10 | 25915.67 | |
| 3868.655 | 20 | 25841.45 | $4d\ ^2D_{2\frac{1}{2}} - 5f\ ^4F^\circ_{3\frac{1}{2}}$ |
| 3870.630 | 20 | 25828.27 | $4d\ ^2D_{2\frac{1}{2}} - 5f\ ^4D^\circ_{2\frac{1}{2}}$ |
| 3875.382 | 3 | 25796.60 | $4d\ ^2D_{2\frac{1}{2}} - 5f\ ^4P^\circ_{1\frac{1}{2}}$ |
| 3878.692 | 10 | 25774.58 | $4p\ ^4D^\circ_{3\frac{1}{2}} - s^2\ ^2D_{2\frac{1}{2}}$ |
| 3879.910 | 60 | 25766.49 | $5p\ ^4D^\circ_{3\frac{1}{2}} - 6d\ ^4F_{4\frac{1}{2}}$ |
| 3881.715 | 10 | 25754.51 | $4p''\ ^4P^\circ_{2\frac{1}{2}} - 5s\ ^4F_{3\frac{1}{2}}$ |
| 3898.314 | 100 | 25644.85 | $5p\ ^4D^\circ_{3\frac{1}{2}} - 6d\ ^4D_{3\frac{1}{2}}$ |
| 3898.833 | 20 | 25641.44 | $5p\ ^4D^\circ_{3\frac{1}{2}} - 7s\ ^4F_{2\frac{1}{2}}$ |
| 3900.121 | 2 | 25632.97 | $5p\ ^4D^\circ_{0\frac{1}{2}} - 6d\ ^2P_{0\frac{1}{2}}$ |
| 3900.350 | 40 | 25631.46 | $5p\ ^4D^\circ_{3\frac{1}{2}} - 6d\ ^4P_{2\frac{1}{2}}$ |
| 3902.307 | 2 | 25618.61 | $5p\ ^4D^\circ_{3\frac{1}{2}} - 7s\ ^2F_{3\frac{1}{2}}$ |
| 3902.806 | 2 | 25615.33 | |
| 3905.489 | 40 | 25597.74 | |
| 3906.343 | 15 | 25592.14 | $5p\ ^4D^\circ_{1\frac{1}{2}} - 6d\ ^2D_{2\frac{1}{2}}$ |
| 3912.135 | 20 | 25554.25 | |
| 3915.383 | 40 | 25533.05 | $5p\ ^4G^\circ_{3\frac{1}{2}} - 6d\ ^2D_{2\frac{1}{2}}$ |
| 3920.078 | 40 | 25502.47 | $5p\ ^4D^\circ_{1\frac{1}{2}} - 6d\ ^4D_{1\frac{1}{2}}$ |
| 3920.651 | 5 | 25498.75 | |
| 3923.097 | 10 | 25482.85 | $5s''\ ^4P_{2\frac{1}{2}} - s\ ^4D^\circ_{3\frac{1}{2}}$ |
| 3932.051 | 2 | 25424.82 | $5s'''\ ^4P_{1\frac{1}{2}} - s\ ^4D^\circ_{2\frac{1}{2}}$ |
| 3932.458 | 10 | 25422.19 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 6d\ ^4G_{4\frac{1}{2}}$ |
| 3936.944 | 10 | 25393.22 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 6d\ ^4F_{3\frac{1}{2}}$ |
| 3937.797 | 50 | 25387.72 | $5p\ ^4G^\circ_{2\frac{1}{2}} - 6d\ ^4G_{2\frac{1}{2}}$ |
| 3941.599 | 20 | 25363.23 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 6d\ ^2D_{2\frac{1}{2}}$ |
| 3943.044 | 200 | 25353.94 | $5p\ ^4G^\circ_{2\frac{1}{2}} - 6d\ ^4H_{3\frac{1}{2}}$ |
| 3944.746 | 3 | 25343.00 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 6d\ ^4G_{5\frac{1}{2}}$ |
| 3945.350 | 40 | 25339.12 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^4D_{2\frac{1}{2}}$ |
| 3945.437 | 100 | 25338.56 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 6d\ ^4F_{4\frac{1}{2}}$ |
| 3945.642 | 10 | 25337.25 | $5p\ ^4G^\circ_{2\frac{1}{2}} - 6d\ ^4F_{1\frac{1}{2}}$ |
| 3947.498 | 5 | 25325.33 | |
| 3948.823 | 40 | 25316.84 | $5p\ ^4G^\circ_{3\frac{1}{2}} - 6d\ ^4G_{3\frac{1}{2}}$ |
| 3949.107 | 200 | 25315.02 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 6d\ ^4H_{5\frac{1}{2}}$ |
| 3951.101 | 3 | 25302.24 | $5p\ ^2G^\circ_{3\frac{1}{2}} - 6d\ ^2G_{4\frac{1}{2}}$ |
| 3951.207 | 75 | 25301.56 | $5p\ ^4F^\circ_{1\frac{1}{2}} - 6d\ ^4G_{2\frac{1}{2}}$ |
| 3952.907 | 30 | 25290.68 | $5p\ ^4D^\circ_{1\frac{1}{2}} - 6d\ ^4F_{2\frac{1}{2}}$ |
| 3955.095 | 30 | 25276.69 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 6d\ ^4G_{5\frac{1}{2}}$ |
| 3955.593 | 20 | 25273.51 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 6d\ ^4D_{1\frac{1}{2}}$ |
| 3955.789 | 25 | 25272.26 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 6d\ ^4F_{4\frac{1}{2}}$ |
| 3955.985 | 30 | 25271.00 | $5p\ ^4D^\circ_{1\frac{1}{2}} - 6d\ ^4P_{0\frac{1}{2}}$ |
| 3956.742 | 2 | 25266.17 | $5p\ ^4G^\circ_{3\frac{1}{2}} - 6d\ ^2F_{3\frac{1}{2}}$ |
| 3957.951 | 200 | 25258.45 | $5p\ ^4G^\circ_{3\frac{1}{2}} - 6d\ ^4H_{4\frac{1}{2}}$ |
| 3959.091 | 50 | 25251.18 | $5p\ ^4F^\circ_{1\frac{1}{2}} - 6d\ ^4F_{1\frac{1}{2}}$ |
| 3959.475 | 75 | 25248.73 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 6d\ ^4H_{5\frac{1}{2}}$ |
| 3963.888 | 300 | 25220.62 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 6d\ ^4H_{6\frac{1}{2}}$ |
| 3965.171 | 100 | 25212.46 | $5p\ ^2G^\circ_{4\frac{1}{2}} - 6d\ ^2G_{4\frac{1}{2}}$ |
| 3966.351 | 150 | 25204.96 | $Rp\ ^4G^\circ_{4\frac{1}{2}} - 6d\ ^4G_{4\frac{1}{2}}$ |
| 3966.586 | 30 | 25203.47 | |
| 3967.794 | 30 | 25195.79 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 6d\ ^4D_{2\frac{1}{2}}$ |
| 3968.085 | 40 | 25193.95 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 6d\ ^2D_{2\frac{1}{2}}$ |
| 3970.851 | 10 | 25176.40 | $5p\ ^2G^\circ_{4\frac{1}{2}} - 6d\ ^2F_{3\frac{1}{2}}$ |
| 3970.911 | 2 | 25176.02 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 6d\ ^4F_{3\frac{1}{2}}$ |
| 3970.957 | 5 | 25175.72 | $5p\ ^2G^\circ_{3\frac{1}{2}} - 6d\ ^2F_{2\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II — Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 3971.736 | 100 | 25170.79 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 6d\ ^2D_{2\frac{1}{2}}$ |
| 3973.101 | 400 | 25162.14 | $5p\ ^2G^\circ_{4\frac{1}{2}} - 6d\ ^2H_{5\frac{1}{2}}$ |
| 3973.425 | 3h | 25160.09 | $5s''\ ^4P_{2\frac{1}{2}} - v\ ^4F^\circ_{3\frac{1}{2}}$ |
| 3973.923 | 2 | 25156.93 | |
| 3974.099 | 1 | 25155.82 | |
| 3975.471 | 100 | 25147.14 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 6d\ ^4G_{3\frac{1}{2}}$ |
| 3976.737 | 3 | 25139.13 | |
| 3978.153 | 75 | 25130.19 | $5p\ ^2G^\circ_{3\frac{1}{2}} - 6d\ ^2G_{3\frac{1}{2}}$ |
| 3978.840 | 200 | 25125.85 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 6d\ ^4G_{5\frac{1}{2}}$ |
| 3979.543 | 50 | 25121.41 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 6d\ ^4F_{4\frac{1}{2}}$ |
| 3988.335 | 200 | 25066.03 | $5p\ ^2G^\circ_{3\frac{1}{2}} - 6d\ ^2H_{4\frac{1}{2}}$ |
| 3989.021 | 60 | 25061.72 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 6d\ ^4F_{2\frac{1}{2}}$ |
| 3999.651 | 30 | 24995.11 | |
| 4001.060 | 25 | 24986.31 | |
| 4002.418 | 5 | 24977.83 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 6d\ ^4G_{3\frac{1}{2}}$ |
| 4002.633 | 60 | 24976.49 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^4P_{1\frac{1}{2}}$ |
| 4003.506 | 30 | 24971.05 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 6d\ ^4F_{3\frac{1}{2}}$ |
| 4004.752 | 150 | 24963.28 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 6d\ ^2G_{4\frac{1}{2}}$ |
| 4006.987 | 3h | 24949.35 | |
| 4007.656 | 10h | 24945.19 | |
| 4009.929 | 3 | 24931.05 | |
| 4010.543 | 100 | 24927.23 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 6d\ ^2F_{3\frac{1}{2}}$ |
| 4013.546 | 10h | 24908.58 | |
| 4014.274 | 25 | 24904.07 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 6d\ ^2F_{3\frac{1}{2}}$ |
| 4015.477 | 3 | 24896.60 | $4s'''\ ^2G_{3\frac{1}{2}} - 4p\ ^2D^\circ_{2\frac{1}{2}}$ |
| 4016.140 | 10 | 24892.49 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 6d\ ^4F_{2\frac{1}{2}}$ |
| 4018.972 | 5h | 24874.95 | |
| 4019.878 | 10 | 24869.35 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 6d\ ^4F_{2\frac{1}{2}}$ |
| 4021.919 | 100 | 24856.73 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 6d\ ^4G_{4\frac{1}{2}}$ |
| 4023.767 | 3 | 24845.31 | $4p'''\ ^2F^\circ_{2\frac{1}{2}} - 4d\ ^2F_{2\frac{1}{2}}$ |
| 4031.702 | 2 | 24796.41 | $5p\ ^4D^\circ_{1\frac{1}{2}} - 7s\ ^2F_{2\frac{1}{2}}$ |
| 4032.340 | 20 | 24792.49 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 5s\ ^2F_{3\frac{1}{2}}$ |
| 4035.500 | 2 | 24773.08 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 6d\ ^4F_{4\frac{1}{2}}$ |
| 4036.241 | 10 | 24768.53 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 7s\ ^2F_{3\frac{1}{2}}$ |
| 4045.138 | 50 | 24714.05 | $5p\ ^2F^\circ_{2\frac{1}{2}} - 6d\ ^2F_{2\frac{1}{2}}$ |
| 4050.910 | 20 | 24678.84 | $4p'\ ^2F^\circ_{2\frac{1}{2}} - s^2\ ^2F_{2\frac{1}{2}}$ |
| 4052.603 | 50 | 24668.53 | $5p\ ^2F^\circ_{2\frac{1}{2}} - 6d\ ^2G_{3\frac{1}{2}}$ |
| 4053.860 | 10 | 24660.88 | $4p'\ ^2F^\circ_{3\frac{1}{2}} - s^2\ ^2F_{3\frac{1}{2}}$ |
| 4054.963 | 30 | 24654.17 | $5p\ ^2D^\circ_{1\frac{1}{2}} - 6d\ ^2F_{2\frac{1}{2}}$ |
| 4057.627 | 2 | 24637.99 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 6d\ ^4P_{2\frac{1}{2}}$ |
| 4059.734 | 3 | 24625.20 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 7s\ ^2F_{3\frac{1}{2}}$ |
| 4067.033 | 15 | 24581.01 | $4s'''\ ^2G_{4\frac{1}{2}} - 4p\ ^2F^\circ_{3\frac{1}{2}}$ |
| 4070.814 | 3 | 24558.18 | $4p'''\ ^2F^\circ_{3\frac{1}{2}} - 4d\ ^2F_{3\frac{1}{2}}$ |
| 4078.204 | 30 | 24513.68 | $5p\ ^2D^\circ_{1\frac{1}{2}} - 6d\ ^2P_{0\frac{1}{2}}$ |
| 4127.719 | 2 | 24219.62 | $5s'\ ^2D_{2\frac{1}{2}} - 5f\ ^2D^\circ_{2\frac{1}{2}}$ |
| 4127.793 | 10 | 24219.19 | $4p'\ ^2D^\circ_{1\frac{1}{2}} - s^2\ ^2F_{2\frac{1}{2}}$ |
| 4128.661 | 40 | 24214.10 | $5p\ ^4D^\circ_{3\frac{1}{2}} - 7s\ ^4F_{4\frac{1}{2}}$ |
| 4146.067 | 10 | 24112.44 | $5p\ ^4D^\circ_{0\frac{1}{2}} - 7s\ ^4F_{1\frac{1}{2}}$ |
| 4168.763 | 5 | 23981.17 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 6d\ ^4D_{2\frac{1}{2}}$ |
| 4181.078 | 20 | 23910.54 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 7s\ ^4F_{3\frac{1}{2}}$ |
| 4183.085 | 5 | 23899.07 | |
| 4187.837 | 2 | 23871.95 | $4s'''\ ^2G_{4\frac{1}{2}} - 4p\ ^2G^\circ_{3\frac{1}{2}}$ |
| 4190.872 | 10 | 23854.66 | $5p\ ^4D^\circ_{1\frac{1}{2}} - 7s\ ^4F_{2\frac{1}{2}}$ |
| 4191.334 | 40 | 23852.03 | $5p\ ^4G^\circ_{2\frac{1}{2}} - 7s\ ^4F_{1\frac{1}{2}}$ |
| 4200.698 | 3 | 23798.86 | $5p\ ^4G^\circ_{3\frac{1}{2}} - 6d\ ^4D_{3\frac{1}{2}}$ |
| 4201.299 | 30 | 23795.46 | $5p\ ^4G^\circ_{3\frac{1}{2}} - 7s\ ^4F_{2\frac{1}{2}}$ |
| 4202.950 | 40 | 23786.11 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 7s\ ^4F_{4\frac{1}{2}}$ |
| 4206.111 | 2 | 23768.24 | |
| 4206.526 | 30 | 23765.89 | $5p\ ^4F^\circ_{1\frac{1}{2}} - 7s\ ^4F_{1\frac{1}{2}}$ |
| 4212.231 | 10 | 23733.70 | $5p\ ^2F^\circ_{2\frac{1}{2}} - 6d\ ^4G_{3\frac{1}{2}}$ |
| 4214.700 | 100 | 23719.80 | $5p\ ^4G^\circ_{5\frac{1}{2}} - 7s\ ^4F_{4\frac{1}{2}}$ |
| 4219.412 | 50 | 23693.31 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 7s\ ^4F_{3\frac{1}{2}}$ |
| 4221.280 | 60 | 23682.83 | $5p\ ^2G^\circ_{4\frac{1}{2}} - 7s\ ^2F_{3\frac{1}{2}}$ |
| 4223.767 | 2 | 23668.88 | $4p'\ ^2F^\circ_{3\frac{1}{2}} - 5s\ ^4F_{4\frac{1}{2}}$ |
| 4224.423 | 10 | 23665.21 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 6d\ ^4G_{4\frac{1}{2}}$ |
| 4229.598 | 10 | 23636.25 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 6d\ ^4F_{3\frac{1}{2}}$ |
| 4230.867 | 2 | 23629.16 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 6d\ ^4D_{3\frac{1}{2}}$ |
| 4231.479 | 30 | 23625.75 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 7s\ ^4F_{2\frac{1}{2}}$ |
| 4232.766 | 20 | 23618.56 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 6d\ ^4P_{1\frac{1}{2}}$ |
| 4233.273 | 40 | 23615.73 | $5p\ ^2G^\circ_{3\frac{1}{2}} - 7s\ ^2F_{2\frac{1}{2}}$ |
| 4233.745 | 3 | 23613.10 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 6d\ ^4F_{3\frac{1}{2}}$ |
| 4236.611 | 2 | 23597.13 | |
| 4237.907 | 5 | 23589.91 | $4p'\ ^2D^\circ_{2\frac{1}{2}} - 5s\ ^4F_{3\frac{1}{2}}$ |
| 4238.166 | 2 | 23588.47 | $5p\ ^2D^\circ_{1\frac{1}{2}} - 6d\ ^4F_{2\frac{1}{2}}$ |
| 4241.684 | 30 | 23568.91 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 7s\ ^4F_{4\frac{1}{2}}$ |
| 4249.567 | 2 | 23525.19 | |
| 4256.235 | 10 | 23488.33 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 7s\ ^4F_{3\frac{1}{2}}$ |
| 4258.820 | 40 | 23474.07 | $4p\ ^4G^\circ_{3\frac{1}{2}} - s^2\ ^2H_{4\frac{1}{2}}$ |
| 4266.159 | 40 | 23433.69 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 7s\ ^2F_{3\frac{1}{2}}$ |
| 4270.381 | 20 | 23410.53 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 7s\ ^2F_{3\frac{1}{2}}$ |
| 4278.546 | 2 | 23365.85 | $x\ ^4G^\circ_{3\frac{1}{2}} - 9s\ ^4F_{2\frac{1}{2}}$ |
| 4279.210 | 200 | 23362.22 | $4p\ ^4G^\circ_{4\frac{1}{2}} - s^2\ ^2H_{5\frac{1}{2}}$ |
| 4279.545 | 1 | 23360.40 | $4p''\ ^4D^\circ_{1\frac{1}{2}} - 5s\ ^4F_{1\frac{1}{2}}$ |
| 4282.360 | 15 | 23345.04 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 7s\ ^4F_{3\frac{1}{2}}$ |
| 4285.028 | 2 | 23330.51 | |
| 4287.251 | 2 | 23318.41 | $4p''\ ^4D^\circ_{0\frac{1}{2}} - 5s\ ^4F_{1\frac{1}{2}}$ |
| 4314.567 | 3 | 23170.78 | |
| 4317.688 | 30 | 23154.03 | $5p\ ^2F^\circ_{2\frac{1}{2}} - 7s\ ^2F_{2\frac{1}{2}}$ |
| 4328.883 | 20 | 23094.15 | $5p\ ^2D^\circ_{1\frac{1}{2}} - 7s\ ^2F_{2\frac{1}{2}}$ |
| 4362.104 | 1 | 22918.28 | $4s'''\ ^2G_{4\frac{1}{2}} - 4p\ ^4F^\circ_{3\frac{1}{2}}$ |
| 4363.707 | 2 | 22909.86 | |
| 4366.927 | 2 | 22892.96 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - 5s\ ^2F_{3\frac{1}{2}}$ |
| 4401.032 | 5 | 22715.56 | $4d'\ ^2F_{3\frac{1}{2}} - 4f'''\ ^4F^\circ_{4\frac{1}{2}}$ |
| 4422.364 | 5 | 22605.99 | $4d'\ ^2D_{1\frac{1}{2}} - 4f'''\ ^2D^\circ_{2\frac{1}{2}}$ |
| 4432.438 | 5 | 22554.61 | $4d'\ ^2D_{1\frac{1}{2}} - 4f'''\ ^4F^\circ_{2\frac{1}{2}}$ |
| 4454.942 | 3 | 22440.68 | $4d'\ ^2P_{1\frac{1}{2}} - 4f'''\ ^4D^\circ_{2\frac{1}{2}}$ |
| 4479.226 | 40 | 22319.02 | $4p\ ^4F^\circ_{3\frac{1}{2}} - s^2\ ^2H_{4\frac{1}{2}}$ |
| 4509.269 | 200 | 22170.33 | $4p\ ^4F^\circ_{3\frac{1}{2}} - s^2\ ^2H_{5\frac{1}{2}}$ |
| 4512.040 | 2 | 22156.71 | $4p''\ ^4D^\circ_{2\frac{1}{2}} - s^2\ ^2F_{3\frac{1}{2}}$ |
| 4517.399 | 5 | 22130.43 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 7s\ ^4F_{3\frac{1}{2}}$ |
| 4522.349 | 3 | 22106.20 | $4d\ ^4P_{1\frac{1}{2}} - 4f\ ^4G^\circ_{2\frac{1}{2}}$ |
| 4532.324 | 20 | 22057.55 | $4d'\ ^2D_{2\frac{1}{2}} - 4f'''\ ^2G^\circ_{3\frac{1}{2}}$<br>$4s'''\ ^2G_{4\frac{1}{2}} - 4p\ ^4F^\circ_{4\frac{1}{2}}$ |
| 4533.002 | 10 | 22054.25 | $4d'\ ^2D_{2\frac{1}{2}} - 4f'''\ ^4F^\circ_{2\frac{1}{2}}$ |
| 4533.297 | 10 | 22052.82 | $4d'\ ^2P_{1\frac{1}{2}} - 4f'''\ ^4F^\circ_{2\frac{1}{2}}$ |
| 4536.508 | 8 | 22037.21 | $4d'\ ^2D_{2\frac{1}{2}} - 4f'''\ ^4F^\circ_{3\frac{1}{2}}$ |
| 4545.550 | 30 | 21993.37 | $4d'\ ^2D_{2\frac{1}{2}} - 4f'''\ ^2F^\circ_{3\frac{1}{2}}$ |
| 4561.885 | 5 | 21914.62 | $4p\ ^4F^\circ_{3\frac{1}{2}} - s^2\ ^2D_{2\frac{1}{2}}$ |
| 4582.971 | 10 | 21813.79 | $4d\ ^4D_{3\frac{1}{2}} - 4f\ ^2G^\circ_{4\frac{1}{2}}$ |
| 4589.472 | 3 | 21782.90 | $4d\ ^4D_{3\frac{1}{2}} - 4f\ ^4G^\circ_{3\frac{1}{2}}$ |
| 4633.182 | 5 | 21577.40 | |
| 4637.338 | 5 | 21558.06 | |
| 4665.559 | 200 | 21427.66 | $4p\ ^2G^\circ_{4\frac{1}{2}} - s^2\ ^2H_{5\frac{1}{2}}$ |
| 4679.160 | 200 | 21365.38 | $4p\ ^2G^\circ_{3\frac{1}{2}} - s^2\ ^2H_{4\frac{1}{2}}$ |
| 4695.696 | 5 | 21290.14 | |
| 4704.831 | 10 | 21248.80 | $4d\ ^4H_{5\frac{1}{2}} - 4f\ ^2I^\circ_{6\frac{1}{2}}$ |
| 4705.073 | 30 | 21247.71 | $4d''\ ^4D_{2\frac{1}{2}} - 4f'''\ ^2F^\circ_{2\frac{1}{2}}$ |
| 4723.968 | 2 | 21162.72 | $4d\ ^4P_{1\frac{1}{2}} - 4f\ ^4F^\circ_{2\frac{1}{2}}$ |
| 4724.931 | 1 | 21158.41 | $4d\ ^4P_{1\frac{1}{2}} - 4f\ ^2P^\circ_{1\frac{1}{2}}$ |
| 4725.630 | 0 | 21155.28 | $4p\ ^4D^\circ_{2\frac{1}{2}} - s^2\ ^2P_{1\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition | λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|---|---|---|---|
| 4726.441 | 2 | 21151.61 | $4d\,^4P_{0\frac{1}{2}} - 4f\,^4F^\circ_{1\frac{1}{2}}$ | 4886.283 | 60 | 20459.74 | $4d\,^4D^\circ_{3\frac{1}{2}} - 4f\,^4F^\circ_{4\frac{1}{2}}$ |
| 4734.111 | 10 | 21117.38 | $4d'\,^2G_{2\frac{1}{2}} - 6f\,^4D^\circ_{2\frac{1}{2}}$ | 4887.193 | 5 | 20455.93 | $4d\,^4D_{3\frac{1}{2}} - 4f\,^4F^\circ_{3\frac{1}{2}}$ |
| | | | $4d''\,^4D_{3\frac{1}{2}} - 4f'''\,^4D^\circ_{3\frac{1}{2}}$ | 4887.736 | 40 | 20453.66 | |
| 4741.527 | 3 | 21084.35 | | 4889.305 | 50 | 20447.09 | $4d\,^4D_{3\frac{1}{2}} - 4f\,^4G^\circ_{4\frac{1}{2}}$ |
| 4742.375 | 2 | 21080.58 | $4d\,^4P_{0\frac{1}{2}} - 5f\,^4D^\circ_{0\frac{1}{2}}$ | 4893.225 | 1 | 20430.71 | $4d\,^4D_{3\frac{1}{2}} - 4f\,^4D^\circ_{2\frac{1}{2}}$ |
| 4742.698 | 5 | 21079.15 | $4d''\,^4D_{2\frac{1}{2}} - 4f'''\,^4D^\circ_{3\frac{1}{2}}$ | 4895.260 | 8 | 20422.22 | |
| 4745.163 | 5 | 21068.20 | $4d\,^2P_{1\frac{1}{2}} - 4f\,^4G^\circ_{2\frac{1}{2}}$ | 4897.587 | 1 | 20412.52 | |
| 4746.002 | 5 | 21064.47 | | 4898.950 | 100 | 20406.84 | $4d\,^4D_{3\frac{1}{2}} - 4f\,^4D^\circ_{3\frac{1}{2}}$ |
| 4755.597 | 5 | 21021.98 | $4p''\,^4D^\circ_{3\frac{1}{2}} - 5s\,^4F_{4\frac{1}{2}}$ | 4902.137 | 10 | 20393.57 | |
| 4755.752 | 8 | 21021.29 | $4p''\,^2D^\circ_{2\frac{1}{2}} - s^2\,^2F_{3\frac{1}{2}}$ | 4903.865 | 10 | 20386.39 | |
| 4757.671 | 20 | 21012.81 | $4d''\,^4D_{3\frac{1}{2}} - 4f'''\,^4D^\circ_{2\frac{1}{2}}$ | 4909.746 | 10 | 20361.97 | $4d\,^4P_{2\frac{1}{2}} - 4f\,^4F^\circ_{3\frac{1}{2}}$ |
| 4766.370 | 2 | 20974.46 | $4d''\,^4D_{2\frac{1}{2}} - 4f'''\,^4D^\circ_{2\frac{1}{2}}$ | 4909.889 | 100 | 20361.37 | $4d\,^4D_{3\frac{1}{2}} - 4f\,^4P^\circ_{2\frac{1}{2}}$ |
| 4768.805 | 2 | 20963.75 | $4d\,^2P_{1\frac{1}{2}} - 4f\,^2D^\circ_{1\frac{1}{2}}$ | 4911.570 | 20 | 20354.41 | |
| 4769.418 | 2 | 20961.06 | $4p\,^2G^\circ_{3\frac{1}{2}} - s^2\,^2D_{2\frac{1}{2}}$ | 4915.840 | 15 | 20336.73 | $4d\,^4P_{2\frac{1}{2}} - 4f\,^4D^\circ_{2\frac{1}{2}}$ |
| 4774.083 | 3 | 20940.58 | $4d\,^4F_{3\frac{1}{2}} - 4f\,^2G^\circ_{4\frac{1}{2}}$ | 4920.771 | 3 | 20316.35 | $4d\,^4D_{0\frac{1}{2}} - 4f\,^4F^\circ_{1\frac{1}{2}}$ |
| 4781.765 | 40 | 20906.94 | $4d''\,^4D_{1\frac{1}{2}} - 4f'''\,^4D^\circ_{2\frac{1}{2}}$ | 4920.889 | 3 | 20315.86 | $4d\,^4P_{2\frac{1}{2}} - 4f\,^4P^\circ_{1\frac{1}{2}}$ |
| 4781.963 | 20 | 20906.07 | | 4923.328 | 3 | 20305.80 | |
| 4789.227 | 5 | 20874.36 | | 4925.657 | 2 | 20296.19 | $4d'\,^2F_{2\frac{1}{2}} - 4f'\,^2P^\circ_{1\frac{1}{2}}$ |
| 4797.523 | 3 | 20838.26 | $4d\,^4G_{4\frac{1}{2}} - 4f\,^2G^\circ_{4\frac{1}{2}}$ | 4932.460 | 5 | 20268.20 | |
| 4799.968 | 10 | 20827.65 | $4d\,^4G_{4\frac{1}{2}} - 4f\,^2H^\circ_{5\frac{1}{2}}$ | 4932.657 | 100 | 20267.39 | $4d\,^4P_{2\frac{1}{2}} - 4f\,^4P^\circ_{2\frac{1}{2}}$ |
| 4802.150 | 30 | 20818.19 | | 4936.319 | 0 | 20252.36 | $4d''\,^2D_{2\frac{1}{2}} - 4f''\,^2F^\circ_{2\frac{1}{2}}$ |
| 4808.883 | 1 | 20789.04 | $4d\,^4F_{2\frac{1}{2}} - 4f\,^2G^\circ_{3\frac{1}{2}}$ | 4936.419 | 10 | 20251.95 | $4p\,^2F^\circ_{3\frac{1}{2}} - s^2\,^2D_{2\frac{1}{2}}$ |
| 4808.958 | 10 | 20788.72 | $4d\,^4H_{4\frac{1}{2}} - 4f\,^2I^\circ_{5\frac{1}{2}}$ | 4937.352 | 20 | 20248.12 | $4d\,^4P_{2\frac{1}{2}} - 4f\,^4S^\circ_{1\frac{1}{2}}$? |
| 4811.448 | 3 | 20777.96 | $4d''\,^4D_{2\frac{1}{2}} - 4f'''\,^4D^\circ_{1\frac{1}{2}}$ | 4938.050 | 50 | 20245.26 | $4d\,^4D_{0\frac{1}{2}} - 4f\,^4D^\circ_{0\frac{1}{2}}$ |
| 4813.651 | 5 | 20768.45 | $4d\,^4G_{4\frac{1}{2}} - 4f\,^4I^\circ_{5\frac{1}{2}}$ | 4938.630 | 100 | 20242.88 | |
| 4822.023 | 2 | 20732.39 | | 4939.917 | 3 | 20237.61 | $4d\,^4D_{2\frac{1}{2}} - 5p''\,^4P^\circ_{2\frac{1}{2}}$ |
| 4823.045 | 5 | 20728.00 | $4d''\,^4D_{1\frac{1}{2}} - 4f'''\,^4D^\circ_{0\frac{1}{2}}$ | 4940.031 | 2 | 20237.14 | |
| 4823.493 | 5 | 20726.07 | $4d'\,^2F_{3\frac{1}{2}} - w\,^2G^\circ_{4\frac{1}{2}}$ | 4942.786 | 20 | 20225.86 | $4d'\,^2F_{2\frac{1}{2}} - 4f'\,^2D^\circ_{2\frac{1}{2}}$ |
| 4826.626 | 10 | 20712.62 | $4d\,^4D_{2\frac{1}{2}} - 4f\,^2D^\circ_{2\frac{1}{2}}$ | 4945.990 | 20 | 20212.76 | $4d\,^4P_{0\frac{1}{2}} - 4f\,^4D^\circ_{1\frac{1}{2}}$ |
| 4827.127 | 15 | 20710.47 | $4d''\,^4D_{1\frac{1}{2}} - 4f'''\,^4D^\circ_{1\frac{1}{2}}$ | 4949.847 | 0 | 20197.01 | $4d\,^4D_{0\frac{1}{2}} - 4f\,^2D^\circ_{1\frac{1}{2}}$ |
| 4827.357 | 20 | 20709.48 | $4d\,^4D_{2\frac{1}{2}} - 4f\,^2F^\circ_{3\frac{1}{2}}$ | 4950.771 | 20 | 20193.24 | $4d\,^2P_{1\frac{1}{2}} - 4f\,^2D^\circ_{2\frac{1}{2}}$ |
| 4829.487 | 5 | 20700.35 | $4d''\,^4D_{0\frac{1}{2}} - 4f'''\,^4D^\circ_{0\frac{1}{2}}$ | 4950.970 | 5 | 20192.43 | $4d'\,^2F_{3\frac{1}{2}} - 4f'\,^2D^\circ_{2\frac{1}{2}}$ |
| 4831.710 | 30 | 20690.82 | $4d\,^4D_{2\frac{1}{2}} - 4f\,^4G^\circ_{3\frac{1}{2}}$ | 4952.880 | 2 | 20184.64 | |
| 4835.451 | 2 | 20674.82 | | 4953.317 | 3 | 20182.86 | $4d'\,^2F_{2\frac{1}{2}} - 4f'\,^2F^\circ_{3\frac{1}{2}}$ |
| 4836.367 | 5 | 20670.90 | $4d\,^4D_{1\frac{1}{2}} - 4f\,^4F^\circ_{1\frac{1}{2}}$ | 4954.167 | 20 | 20179.40 | $4d\,^4P_{0\frac{1}{2}} - 4f\,^2P^\circ_{0\frac{1}{2}}$ |
| 4839.787 | 30 | 20656.29 | $4p\,^2F^\circ_{3\frac{1}{2}} - s^2\,^2H_{4\frac{1}{2}}$ | 4957.478 | 10 | 20165.92 | $4d''\,^4F_{2\frac{1}{2}} - 4f'''\,^2F^\circ_{2\frac{1}{2}}$ |
| 4839.859 | 40 | 20655.99 | $4d\,^4D_{1\frac{1}{2}} - 4f\,^4G^\circ_{2\frac{1}{2}}$ | 4958.879 | 200 | 20160.22 | $4d'\,^2F_{2\frac{1}{2}} - 4f'\,^2G^\circ_{3\frac{1}{2}}$ |
| 4841.369 | 2 | 20649.55 | $4d\,^2F_{3\frac{1}{2}} - 4f\,^4I^\circ_{4\frac{1}{2}}$ | 4959.192 | 40 | 20158.95 | |
| 4842.636 | 40 | 20644.14 | $4d\,^4D_{2\frac{1}{2}} - 4f\,^4F^\circ_{2\frac{1}{2}}$ | 4959.846 | 1 | 20156.29 | $4d\,^4P_{0\frac{1}{2}} - 5p''\,^4P^\circ_{1\frac{1}{2}}$ |
| 4843.652 | 15 | 20639.81 | $4d\,^4D_{2\frac{1}{2}} - 4f\,^2P^\circ_{1\frac{1}{2}}$ | 4961.539 | 50 | 20149.41 | $4d'\,^2F_{3\frac{1}{2}} - 4f'\,^2F^\circ_{3\frac{1}{2}}$ |
| 4844.081 | 20 | 20637.98 | $4d''\,^4D_{2\frac{1}{2}} - 4f'''\,^2D^\circ_{2\frac{1}{2}}$ | 4962.844 | 20 | 20144.12 | $4d\,^2P_{1\frac{1}{2}} - 4f\,^4D^\circ_{1\frac{1}{2}}$ |
| 4848.701 | 2 | 20618.32 | $4d''\,^4D_{2\frac{1}{2}} - 4f'''\,^4F^\circ_{1\frac{1}{2}}$ | 4967.116 | 15 | 20126.79 | $4d'\,^2F_{3\frac{1}{2}} - 4f'''\,^4D^\circ_{3\frac{1}{2}}$ |
| 4851.169 | 60 | 20607.83 | $4d''\,^4D_{3\frac{1}{2}} - 4f'''\,^4F^\circ_{3\frac{1}{2}}$ | 4967.630 | 0 | 20124.71 | $4d\,^2P_{1\frac{1}{2}} - 4f\,^4F^\circ_{2\frac{1}{2}}$ |
| 4851.352 | 2 | 20607.05 | $4d\,^4D_{2\frac{1}{2}} - 5p''\,^4P^\circ_{1\frac{1}{2}}$ | 4968.556 | 2 | 20120.96 | |
| 4853.064 | 3 | 20599.78 | $4d\,^4D_{1\frac{1}{2}} - 4f\,^4D^\circ_{0\frac{1}{2}}$ | 4968.685 | 20 | 20120.43 | $4d\,^2P_{1\frac{1}{2}} - 4f\,^2P^\circ_{1\frac{1}{2}}$ |
| 4853.337 | 100 | 20598.63 | $4d''\,^4D_{3\frac{1}{2}} - 4f'''\,^4F^\circ_{4\frac{1}{2}}$ | 4969.533 | 5 | 20117.00 | $4d\,^4H_{6\frac{1}{2}} - 4f\,^4G^\circ_{5\frac{1}{2}}$ |
| 4855.949 | 5 | 20587.55 | $4d\,^4G_{3\frac{1}{2}} - 4f\,^2H^\circ_{4\frac{1}{2}}$ | 4970.017 | 5 | 20115.04 | |
| 4856.164 | 30 | 20586.63 | $4d''\,^4D_{2\frac{1}{2}} - 4f'''\,^4F^\circ_{2\frac{1}{2}}$ | 4971.077 | 15 | 20110.75 | $4d\,^2P_{1\frac{1}{2}} - 4f\,^2P^\circ_{0\frac{1}{2}}$ |
| 4856.420 | 2 | 20585.55 | $4d\,^4G_{3\frac{1}{2}} - 4f\,^2G^\circ_{3\frac{1}{2}}$ | 4971.216 | 0 | 20110.19 | |
| 4856.856 | 2 | 20583.70 | | 4974.122 | 200 | 20098.44 | $4d'\,^2F_{3\frac{1}{2}} - 4f'\,^2G^\circ_{4\frac{1}{2}}$ |
| 4859.987 | 10 | 20570.44 | $4d''\,^4D_{1\frac{1}{2}} - 4f'''\,^2D^\circ_{2\frac{1}{2}}$ | 4975.089 | 0 | 20094.54 | $4d'\,^2D_{1\frac{1}{2}} - 4f'\,^2P^\circ_{0\frac{1}{2}}$ |
| 4860.186 | 100 | 20569.60 | $4d''\,^4D_{2\frac{1}{2}} - 4f'''\,^4F^\circ_{3\frac{1}{2}}$ | 4977.744 | 0 | 20083.82 | $4d''\,^2D_{2\frac{1}{2}} - 4f'''\,^4D^\circ_{3\frac{1}{2}}$ |
| 4864.445 | 5 | 20551.59 | $4d\,^4D_{1\frac{1}{2}} - 4f\,^2D^\circ_{1\frac{1}{2}}$ | 4980.530 | 40 | 20072.58 | |
| 4864.632 | 40 | 20550.80 | $4d''\,^4D_{1\frac{1}{2}} - 4f'''\,^4F^\circ_{1\frac{1}{2}}$ | 4981.005 | 50 | 20070.67 | $4d\,^4H_{6\frac{1}{2}} - 4f\,^4H^\circ_{6\frac{1}{2}}$ |
| 4868.987 | 20 | 20532.42 | $4d\,^4G_{3\frac{1}{2}} - 4f\,^4I^\circ_{4\frac{1}{2}}$ | 4985.579 | 5 | 20052.26 | $4d''\,^4F_{3\frac{1}{2}} - 4f'''\,^4G^\circ_{3\frac{1}{2}}$ |
| 4870.566 | 5 | 20525.76 | $4d''\,^4D_{2\frac{1}{2}} - 4f'''\,^2F^\circ_{3\frac{1}{2}}$ | 4986.719 | 20 | 20047.67 | $4d\,^4H_{3\frac{1}{2}} - 4f\,^4H^\circ_{3\frac{1}{2}}$ |
| 4871.190 | 30 | 20523.13 | $4d''\,^4D_{0\frac{1}{2}} - 4f'''\,^4F^\circ_{1\frac{1}{2}}$ | 4987.037 | 8 | 20046.39 | |
| 4872.147 | 50 | 20519.10 | $4d''\,^4D_{1\frac{1}{2}} - 4f'''\,^4F^\circ_{2\frac{1}{2}}$ | 4987.832 | 40 | 20043.20 | $4d'\,^2F_{2\frac{1}{2}} - 4f'\,^2F^\circ_{2\frac{1}{2}}$ |
| 4876.315 | 2 | 20501.56 | $4d\,^2G_{4\frac{1}{2}} - 4f\,^2I^\circ_{5\frac{1}{2}}$ | 4989.143 | 10 | 20037.93 | |
| 4885.673 | 5 | 20462.29 | $4p\,^2F^\circ_{2\frac{1}{2}} - s^2\,^2D_{1\frac{1}{2}}$ | 4989.645 | 20 | 20035.92 | $4d\,^4H_{3\frac{1}{2}} - 4f\,^2H^\circ_{4\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 4992.024 | 500 | 20026.37 | $4d\,^4H_{6\frac{1}{2}} - 4f\,^4I^\circ_{7\frac{1}{2}}$ |
| 4993.033 | 50 | 20022.32 | $4d''\,^4F_{3\frac{1}{2}} - 4f''\,^4D^\circ_{2\frac{1}{2}}$ |
| 4993.343 | 20 | 20021.08 | $4d'\,^2D_{1\frac{1}{2}} - 4f'\,^2D^\circ_{1\frac{1}{2}}$ |
| 4996.170 | 8 | 20009.75 | $4d'\,^2F_{3\frac{1}{2}} - 4f'\,^2F^\circ_{2\frac{1}{2}}$ |
| 4996.314 | 3 | 20009.17 | $4d''\,^2D_{2\frac{1}{2}} - 4f''\,^4G^\circ_{3\frac{1}{2}}$ |
| 4998.290 | 3 | 20001.26 | |
| 4999.085 | 2 | 19998.08 | $4p''\,^2D^\circ_{1\frac{1}{2}} - s^2\,^2F_{2\frac{1}{2}}$ |
| 4999.271 | 0 | 19997.34 | $4d''\,^4F_{2\frac{1}{2}} - 4f''\,^4D^\circ_{3\frac{1}{2}}$ |
| 5001.366 | 1 | 19988.96 | |
| 5003.413 | 100 | 19980.78 | $4d\,^4H_{3\frac{1}{2}} - 4f\,^4I^\circ_{4\frac{1}{2}}$ |
| 5005.665 | 3 | 19971.79 | $4d\,^2H_{5\frac{1}{2}} - 4f\,^2G^\circ_{4\frac{1}{2}}$ |
| 5006.088 | 20 | 19970.11 | $4d\,^4H_{5\frac{1}{2}} - 4f\,^4G^\circ_{5\frac{1}{2}}$ |
| 5007.165 | 2 | 19965.81 | |
| 5007.305 | 10 | 19965.25 | |
| 5008.328 | 40 | 19961.18 | $4d\,^2H_{5\frac{1}{2}} - 4f\,^2H^\circ_{5\frac{1}{2}}$ |
| 5009.244 | 10 | 19957.53 | $4d\,^4H_{5\frac{1}{2}} - 4f\,^4F^\circ_{4\frac{1}{2}}$ |
| 5010.662 | 30 | 19951.88 | |
| 5011.085 | 2 | 19950.19 | |
| 5011.940 | 10 | 19946.79 | $4d\,^2F_{2\frac{1}{2}} - 4f\,^2F^\circ_{2\frac{1}{2}}$ |
| 5013.536 | 15 | 19940.44 | $4d\,^4H_{4\frac{1}{2}} - 4f\,^4H^\circ_{4\frac{1}{2}}$ |
| 5014.075 | 30 | 19938.30 | $4d\,^4H_{4\frac{1}{2}} - 4f\,^2H^\circ_{5\frac{1}{2}}$ |
| 5014.625 | 20 | 19936.11 | $4d\,^4F_{1\frac{1}{2}} - 4f\,^2F^\circ_{2\frac{1}{2}}$ |
| 5016.542 | 25 | 19928.49 | |
| 5017.728 | 10 | 19923.78 | $4d\,^4H_{5\frac{1}{2}} - 4f\,^4H^\circ_{6\frac{1}{2}}$ |
| 5017.814 | 10 | 19923.44 | $4d\,^4H_{5\frac{1}{2}} - 4f\,^4H^\circ_{5\frac{1}{2}}$ |
| 5018.010 | 20 | 19922.66 | $4d''\,^4F_{2\frac{1}{2}} - 4f''\,^4G^\circ_{3\frac{1}{2}}$ |
| 5019.758 | 5? | 19915.72 | $4d\,^2P_{0\frac{1}{2}} - 4f\,^4F^\circ_{1\frac{1}{2}}$ |
| 5020.081 | 2 | 19914.44 | $4d\,^2F_{2\frac{1}{2}} - 4f\,^4F^\circ_{1\frac{1}{2}}$ |
| 5020.619 | 2 | 19912.31 | $4p\,^2D^\circ_{2\frac{1}{2}} - s^2\,^2D_{2\frac{1}{2}}$ |
| 5021.455 | 200 | 19908.99 | $4d\,^2H_{5\frac{1}{2}} - 4f\,^2I^\circ_{6\frac{1}{2}}$ |
| 5022.226 | 40 | 19905.94 | $4d''\,^4F_{4\frac{1}{2}} - 6f\,^2H^\circ_{5\frac{1}{2}}$ |
| 5022.769 | 5 | 19903.79 | $4d\,^4F_{1\frac{1}{2}} - 4f\,^4F^\circ_{1\frac{1}{2}}$ |
| 5023.220 | 5 | 19902.00 | $4d\,^2H_{5\frac{1}{2}} - 4f\,^4I^\circ_{5\frac{1}{2}}$ |
| 5023.823 | 15 | 19899.61 | $4d\,^2F_{2\frac{1}{2}} - 4f\,^4G^\circ_{2\frac{1}{2}}$ |
| 5026.514 | 15 | 19888.96 | $4d\,^4F_{1\frac{1}{2}} - 4f\,^4G^\circ_{2\frac{1}{2}}$ |
| 5028.158 | 20 | 19882.45 | $4d\,^4F_{2\frac{1}{2}} - 4f\,^2D^\circ_{2\frac{1}{2}}$ |
| 5028.981 | 150 | 19879.20 | $4d\,^4H_{4\frac{1}{2}} - 4f\,^4I^\circ_{5\frac{1}{2}}$ |
| 5029.448 | 2 | 19877.35 | |
| 5032.066 | 0 | 19867.01 | $4d''\,^4F_{4\frac{1}{2}} - 6f\,^4I^\circ_{5\frac{1}{2}}$ |
| 5033.678 | 40 | 19860.65 | $4d\,^4F_{2\frac{1}{2}} - 4f\,^4G^\circ_{3\frac{1}{2}}$ |
| 5033.818 | 1 | 19860.10 | |
| 5034.356 | 1 | 19857.98 | $4d'\,^2G_{4\frac{1}{2}} - 4f'\,^2H^\circ_{4\frac{1}{2}}$ |
| 5034.546 | 20 | 19857.23 | $4d\,^4P_{1\frac{1}{2}} - 4f\,^4D^\circ_{2\frac{1}{2}}$ |
| 5035.520 | 100 | 19853.39 | $4d'\,^2G_{3\frac{1}{2}} - 4f'\,^2H^\circ_{4\frac{1}{2}}$ |
| 5037.748 | 2 | 19844.61 | $4d\,^2P_{0\frac{1}{2}} - 4f\,^4D^\circ_{0\frac{1}{2}}$ |
| 5038.634 | 150 | 19841.12 | $4d'\,^2G_{4\frac{1}{2}} - 4f'\,^2H^\circ_{5\frac{1}{2}}$<br>$4d''\,^4F_{4\frac{1}{2}} - 4f''\,^2G^\circ_{4\frac{1}{2}}$ |
| 5039.836 | 30 | 19836.38 | $4d\,^4P_{1\frac{1}{2}} - 4f\,^4P^\circ_{1\frac{1}{2}}$ |
| 5040.360 | 150 | 19834.32 | $4d\,^4H_{5\frac{1}{2}} - 4f\,^4I^\circ_{5\frac{1}{2}}$ |
| 5040.608 | 3 | 19833.35 | $4d\,^4F_{2\frac{1}{2}} - 4f\,^4D^\circ_{1\frac{1}{2}}$ |
| 5040.775 | 10 | 19832.69 | $4d\,^4F_{1\frac{1}{2}} - 4f\,^4D^\circ_{0\frac{1}{2}}$ |
| 5040.924 | 30 | 19832.10 | |
| 5041.841 | 20 | 19828.50 | |
| 5041.954 | 10 | 19828.05 | $4d\,^4G_{2\frac{1}{2}} - 4f\,^2F^\circ_{2\frac{1}{2}}$ |
| 5042.425 | 100 | 19826.20 | $4d\,^4G_{2\frac{1}{2}} - 4f\,^4H^\circ_{3\frac{1}{2}}$ |
| 5042.732 | 2 | 19824.99 | |
| 5043.147 | 20 | 19823.36 | $4d\,^2H_{4\frac{1}{2}} - 4f\,^2H^\circ_{4\frac{1}{2}}$ |
| 5043.648 | 2 | 19821.39 | $4d\,^2H_{4\frac{1}{2}} - 4f\,^2G^\circ_{3\frac{1}{2}}$ |
| 5044.105 | 2 | 19819.60 | $4d''\,^4F_{4\frac{1}{2}} - 4f''\,^4G^\circ_{4\frac{1}{2}}$ |
| 5045.533 | 15 | 19813.99 | $4d\,^4F_{2\frac{1}{2}} - 4f\,^4F^\circ_{2\frac{1}{2}}$ |
| 5045.673 | 5 | 19813.44 | $4d''\,^4F_{3\frac{1}{2}} - 6f\,^4H^\circ_{4\frac{1}{2}}$ |
| 5046.969 | 5 | 19808.35 | $4d''\,^2F_{3\frac{1}{2}} - 4f''\,^4D^\circ_{3\frac{1}{2}}$ |
| 5047.359 | 80 | 19806.82 | $4d\,^4G_{5\frac{1}{2}} - 4f\,^4F^\circ_{4\frac{1}{2}}$ |
| 5048.757 | 5 | 19801.33 | $4d''\,^4F_{3\frac{1}{2}} - 6f\,^2G^\circ_{4\frac{1}{2}}$ |
| 5049.236 | 150 | 19799.46 | $4d''\,^4F_{4\frac{1}{2}} - 4f''\,^4G^\circ_{5\frac{1}{2}}$ |
| 5049.938 | 30 | 19796.70 | $4d\,^2F_{3\frac{1}{2}} - 4f\,^4H^\circ_{4\frac{1}{2}}$ |
| 5050.023 | 1 | 19796.37 | $4d\,^2P_{0\frac{1}{2}} - 4f\,^2D^\circ_{1\frac{1}{2}}$ |
| 5050.082 | 5 | 19796.14 | $4d\,^2F_{3\frac{1}{2}} - 4f\,^2D^\circ_{2\frac{1}{2}}$ |
| 5050.330 | 2 | 19795.17 | $4d\,^2F_{2\frac{1}{2}} - 4f\,^2D^\circ_{1\frac{1}{2}}$ |
| 5050.567 | 10 | 19794.24 | $4d\,^4G_{5\frac{1}{2}} - 4f\,^4F^\circ_{4\frac{1}{2}}$ |
| 5050.885 | 40 | 19792.99 | $4d\,^2F_{3\frac{1}{2}} - 4f\,^2F^\circ_{3\frac{1}{2}}$ |
| 5051.812 | 5 | 19789.36 | $4d''\,^4F_{2\frac{1}{2}} - 4f''\,^2D^\circ_{1\frac{1}{2}}$ |
| 5052.185 | 1 | 19787.90 | $4d\,^4P_{1\frac{1}{2}} - 4f\,^4P^\circ_{2\frac{1}{2}}$ |
| 5052.982 | 75 | 19784.78 | $4d\,^4F_{4\frac{1}{2}} - 4f\,^4G^\circ_{5\frac{1}{2}}$ |
| 5053.803 | 10 | 19781.56 | $4d\,^4G_{5\frac{1}{2}} - 4f\,^4G^\circ_{4\frac{1}{2}}$ |
| 5053.931 | 5 | 19781.06 | $4d\,^4D_{1\frac{1}{2}} - 4f\,^2D^\circ_{2\frac{1}{2}}$ |
| 5053.980 | 10 | 19780.87 | $4d\,^4G_{2\frac{1}{2}} - 4f\,^4G^\circ_{2\frac{1}{2}}$ |
| 5055.116 | 15 | 19776.43 | $4d'\,^2P_{0\frac{1}{2}} - 4f'\,^2P^\circ_{0\frac{1}{2}}$ |
| 5055.646 | 10 | 19774.35 | $4d\,^2F_{3\frac{1}{2}} - 4f\,^4G^\circ_{3\frac{1}{2}}$ |
| 5056.194 | 150 | 19772.21 | $4d\,^4F_{4\frac{1}{2}} - 4f\,^4F^\circ_{4\frac{1}{2}}$ |
| 5057.169 | 20 | 19768.40 | $4d\,^4F_{4\frac{1}{2}} - 4f\,^4F^\circ_{3\frac{1}{2}}$ |
| 5057.215 | 2 | 19768.22 | $4d\,^2H_{4\frac{1}{2}} - 4f\,^4I^\circ_{4\frac{1}{2}}$ |
| 5057.659 | 2 | 19766.48 | |
| 5058.376 | 200 | 19763.68 | $4d\,^2H_{4\frac{1}{2}} - 4f\,^2I^\circ_{5\frac{1}{2}}$ |
| 5058.655 | 0 | 19762.59 | $4d'\,^2D_{2\frac{1}{2}} - w\,^2F^\circ_{3\frac{1}{2}}$<br>$4d''\,^2F_{2\frac{1}{2}} - 4f''\,^4D^\circ_{3\frac{1}{2}}$ |
| 5059.197 | 200 | 19760.47 | $4d\,^4G_{5\frac{1}{2}} - 4f\,^4H^\circ_{6\frac{1}{2}}$ |
| 5059.433 | 15 | 19759.55 | $4d\,^4F_{4\frac{1}{2}} - 4f\,^4G^\circ_{4\frac{1}{2}}$ |
| 5064.910 | 40 | 19738.18 | $4d\,^4F_{4\frac{1}{2}} - 4f\,^4H^\circ_{5\frac{1}{2}}$ |
| 5065.982 | 30 | 19734.01 | $4d\,^4P_{1\frac{1}{2}} - 4f\,^2S^\circ_{0\frac{1}{2}}$ |
| 5066.406 | 3 | 19732.36 | |
| 5066.571 | 75 | 19731.71 | $4d''\,^4F_{3\frac{1}{2}} - 4f''\,^4G^\circ_{4\frac{1}{2}}$ |
| 5067.607 | 5 | 19727.68 | $4d\,^2F_{3\frac{1}{2}} - 4f\,^4F^\circ_{2\frac{1}{2}}$ |
| 5069.760 | 30 | 19719.30 | $4d\,^4F_{4\frac{1}{2}} - 4f\,^4D^\circ_{3\frac{1}{2}}$ |
| 5071.487 | 20 | 19712.59 | $4d\,^4D_{1\frac{1}{2}} - 4f\,^4F^\circ_{2\frac{1}{2}}$ |
| 5072.602 | 10 | 19708.25 | $4d\,^4D_{1\frac{1}{2}} - 4f\,^2P^\circ_{1\frac{1}{2}}$ |
| 5073.384 | 2 | 19705.22 | $4d''\,^4F_{4\frac{1}{2}} - 4f''\,^4F^\circ_{3\frac{1}{2}}$ |
| 5073.761 | 80 | 19703.75 | $4d''\,^2F_{3\frac{1}{2}} - 4f''\,^4D^\circ_{2\frac{1}{2}}$ |
| 5073.973 | 40 | 19702.93 | $4d'\,^2P_{0\frac{1}{2}} - 4f'\,^2D^\circ_{1\frac{1}{2}}$ |
| 5075.747 | 30 | 19696.04 | $4d'\,^2G_{4\frac{1}{2}} - 4f'\,^2F^\circ_{3\frac{1}{2}}$<br>$4d''\,^4F_{4\frac{1}{2}} - 4f''\,^4F^\circ_{4\frac{1}{2}}$ |
| 5077.063 | 3 | 19690.94 | |
| 5077.778 | 30 | 19688.17 | $4d\,^4G_{3\frac{1}{2}} - 4f\,^2G^\circ_{4\frac{1}{2}}$ |
| 5077.846 | 30 | 19687.90 | $4d''\,^2F_{2\frac{1}{2}} - 4f''\,^4G^\circ_{3\frac{1}{2}}$ |
| 5079.999 | 75 | 19679.56 | $4d\,^4G_{3\frac{1}{2}} - 4f\,^4H^\circ_{4\frac{1}{2}}$ |
| 5082.199 | 50 | 19671.04 | $4d\,^4G_{5\frac{1}{2}} - 4f\,^4I^\circ_{6\frac{1}{2}}$ |
| 5082.753 | 30 | 19668.89 | $4d'\,^2G_{3\frac{1}{2}} - 4f'\,^2G^\circ_{3\frac{1}{2}}$ |
| 5084.427 | 2 | 19662.42 | |
| 5084.583 | 50 | 19661.82 | $4d\,^2G_{4\frac{1}{2}} - 4f\,^2G^\circ_{4\frac{1}{2}}$ |
| 5085.777 | 40 | 19657.20 | $4d\,^4G_{3\frac{1}{2}} - 4f\,^4G^\circ_{3\frac{1}{2}}$ |
| 5086.539 | 0 | 19654.25 | $4d''\,^2D_{1\frac{1}{2}} - 4f''\,^2F^\circ_{2\frac{1}{2}}$ |
| 5087.139 | 3 | 19651.94 | |
| 5087.328 | 100 | 19651.21 | $4d\,^2G_{4\frac{1}{2}} - 4f\,^2H^\circ_{5\frac{1}{2}}$ |
| 5087.759 | 5 | 19649.54 | $4d\,^2G_{4\frac{1}{2}} - 4f\,^2F^\circ_{3\frac{1}{2}}$ |
| 5088.898 | 40 | 19645.14 | $4d'\,^2G_{4\frac{1}{2}} - 4f'\,^2G^\circ_{4\frac{1}{2}}$ |
| 5089.537 | 2 | 19642.68 | $4d''\,^2D_{2\frac{1}{2}} - 4f''\,^2D^\circ_{2\frac{1}{2}}$ |
| 5090.084 | 5 | 19640.57 | $4d'\,^2G_{3\frac{1}{2}} - 4f'\,^2G^\circ_{4\frac{1}{2}}$ |
| 5090.826 | 2 | 19637.70 | $4d''\,^4F_{3\frac{1}{2}} - 4f''\,^2G^\circ_{3\frac{1}{2}}$ |
| 5091.727 | 10 | 19634.23 | $4d''\,^4F_{3\frac{1}{2}} - 4f''\,^4F^\circ_{2\frac{1}{2}}$? |
| 5092.288 | 1 | 19632.07 | |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition | λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|---|---|---|---|
| 5092.595 | 2 | 19630.88 | $4d\,^2G_{4\frac{1}{2}} - 4f\,^4G^\circ_{3\frac{1}{2}}$ | 5175.139 | 10 | 19317.77 | $4d\,^4D_{2\frac{1}{2}} - 4f\,^4P^\circ_{1\frac{1}{2}}$ |
| 5095.021 | 10 | 19621.54 | | 5175.949 | 5 | 19314.75 | $4d\,^4D_{2\frac{1}{2}} - 4f\,^4D^\circ_{3\frac{1}{2}}$ |
| 5096.109 | 5 | 19617.35 | $4d''\,^4F_{3\frac{1}{2}} - 4f''\,^4F^\circ_{3\frac{1}{2}}$ | 5182.708 | 5 | 19289.56 | $4d''\,^2F_{3\frac{1}{2}} - 4f''\,^4F^\circ_{4\frac{1}{2}}$ |
| 5097.884 | 10 | 19610.52 | $4d\,^4G_{3\frac{1}{2}} - 4f\,^4F^\circ_{2\frac{1}{2}}$ | 5184.140 | 3 | 19284.23 | $4d''\,^2P_{1\frac{1}{2}} - 4f''\,^2F^\circ_{2\frac{1}{2}}$ |
| 5102.026 | 30 | 19594.60 | $4d''\,^2D_{2\frac{1}{2}} - 4f''\,^2G^\circ_{3\frac{1}{2}}$ | 5185.893 | 20 | 19277.71 | $4d''\,^2D_{1\frac{1}{2}} - 4f''\,^2D^\circ_{1\frac{1}{2}}$ |
| 5102.510 | 10 | 19592.74 | $4d''\,^2P_{1\frac{1}{2}} - 4f'\,^2P^\circ_{0\frac{1}{2}}$ | 5187.064 | 25 | 19273.36 | $4d''\,^2F_{2\frac{1}{2}} - 4f''\,^2G^\circ_{3\frac{1}{2}}$ |
| 5102.881 | 5 | 19591.31 | $4d''\,^2D_{2\frac{1}{2}} - 4f''\,^4F^\circ_{2\frac{1}{2}}$ | 5188.166 | 5 | 19269.27 | $4d\,^4D_{2\frac{1}{2}} - 4f\,^4P^\circ_{2\frac{1}{2}}$ |
| 5103.532 | 5 | 19588.81 | | 5192.027 | 5 | 19254.94 | $4d''\,^2F_{3\frac{1}{2}} - 4f''\,^2F^\circ_{3\frac{1}{2}}$ |
| 5104.144 | 40 | 19586.47 | $4d\,^4F_{3\frac{1}{2}} - 4f\,^4F^\circ_{4\frac{1}{2}}$ | 5193.466 | 30 | 19249.60 | |
| 5105.134 | 60 | 19582.67 | $4d\,^4F_{3\frac{1}{2}} - 4f\,^4F^\circ_{3\frac{1}{2}}$ | 5204.392 | 30 | 19209.19 | $4d''\,^2F_{2\frac{1}{2}} - 4f''\,^2F^\circ_{3\frac{1}{2}}$ |
| 5107.076 | 2 | 19575.22 | $4d'\,^2D_{2\frac{1}{2}} - 4f'\,^2P^\circ_{1\frac{1}{2}}$ | 5206.730 | 20 | 19200.57 | $4d''\,^4P_{1\frac{1}{2}} - 4f''\,^2D^\circ_{2\frac{1}{2}}$ |
| 5107.449 | 100 | 19573.79 | $4d\,^4F_{3\frac{1}{2}} - 4f\,^4G^\circ_{4\frac{1}{2}}$ | 5216.798 | 10 | 19163.51 | |
| | | | $4d'\,^2P_{1\frac{1}{2}} - 4f'\,^2P^\circ_{1\frac{1}{2}}$ | 5220.537 | 3 | 19149.79 | |
| 5110.046 | 2 | 19563.84 | | 5221.317 | 20 | 19146.93 | $4d''\,^4P_{2\frac{1}{2}} - 4f''\,^4G^\circ_{3\frac{1}{2}}$ |
| 5111.727 | 20 | 19557.41 | $4d\,^4F_{3\frac{1}{2}} - 4f\,^4D^\circ_{2\frac{1}{2}}$ | 5226.509 | 3 | 19127.91 | $4d\,^4H_{3\frac{1}{2}} - 4f\,^4H^\circ_{4\frac{1}{2}}$ |
| 5112.462 | 1 | 19554.60 | $4d''\,^2F_{2\frac{1}{2}} - 4f''\,^2D^\circ_{1\frac{1}{2}}$ | 5228.757 | 10 | 19119.68 | |
| 5113.176 | 3 | 19551.87 | $4d'\,^2G_{3\frac{1}{2}} - 4f'\,^2F^\circ_{2\frac{1}{2}}$ | 5236.945 | 20 | 19089.79 | |
| 5117.046 | 40 | 19537.08 | $4d''\,^4P_{1\frac{1}{2}} - 4f''\,^4D^\circ_{2\frac{1}{2}}$ | 5249.986 | 20 | 19042.37 | |
| 5118.793 | 40 | 19530.41 | $4d''\,^2D_{2\frac{1}{2}} - 4f''\,^2F^\circ_{3\frac{1}{2}}$ | 5251.225 | 10 | 19037.88 | |
| 5119.809 | 5 | 19526.54 | | 5254.875 | 2 | 19024.65 | $4d\,^2F_{2\frac{1}{2}} - 4f\,^2D^\circ_{2\frac{1}{2}}$ |
| 5121.718 | 0 | 19519.26 | $4d'\,^2P_{1\frac{1}{2}} - 4f'\,^2D^\circ_{1\frac{1}{2}}$ | 5255.750 | 10 | 19021.49 | $4d\,^2F_{2\frac{1}{2}} - 4f\,^2F^\circ_{3\frac{1}{2}}$ |
| 5124.639 | 2 | 19508.13 | $4d''\,^4F_{2\frac{1}{2}} - 4f''\,^2G^\circ_{3\frac{1}{2}}$ | 5257.827 | 2 | 19013.97 | $4d\,^4F_{1\frac{1}{2}} - 4f\,^2D^\circ_{2\frac{1}{2}}$ |
| 5125.505 | 30 | 19504.84 | $4d'\,^2D_{2\frac{1}{2}} - 4f'\,^2D^\circ_{2\frac{1}{2}}$ | 5257.912 | 10 | 19013.66 | $4d''\,^4P_{2\frac{1}{2}} - 4f''\,^2D^\circ_{1\frac{1}{2}}$ |
| | | | $4d''\,^4F_{2\frac{1}{2}} - 4f''\,^4F^\circ_{2\frac{1}{2}}$ | 5260.912 | 5 | 19002.82 | $4d\,^2F_{2\frac{1}{2}} - 4f\,^4G^\circ_{3\frac{1}{2}}$ |
| 5125.885 | 50 | 19503.39 | $4d'\,^2P_{1\frac{1}{2}} - 4f'\,^2D^\circ_{2\frac{1}{2}}$ | 5267.643 | 3 | 18978.54 | |
| 5127.633 | 40 | 19496.74 | $4d\,^4G_{4\frac{1}{2}} - 4f\,^4G^\circ_{5\frac{1}{2}}$ | 5271.450 | 2 | 18964.83 | $4d\,^4F_{1\frac{1}{2}} - 4f\,^4D^\circ_{1\frac{1}{2}}$ |
| 5128.129 | 5 | 19494.86 | $4d''\,^2F_{3\frac{1}{2}} - 6f\,^4H^\circ_{4\frac{1}{2}}$ | 5273.870 | 10 | 18956.13 | $4d\,^2F_{2\frac{1}{2}} - 4f\,^4F^\circ_{2\frac{1}{2}}$ |
| 5130.529 | 75 | 19485.74 | | 5275.067 | 3 | 18951.83 | $4d\,^2F_{2\frac{1}{2}} - 4f\,^2P^\circ_{1\frac{1}{2}}$ |
| 5130.942 | 2 | 19484.17 | $4d\,^4G_{4\frac{1}{2}} - 4f\,^4F^\circ_{4\frac{1}{2}}$ | 5279.694 | 30 | 18935.22 | |
| 5131.945 | 5 | 19480.36 | $4d\,^4G_{4\frac{1}{2}} - 4f\,^4F^\circ_{3\frac{1}{2}}$ | 5288.799 | 10 | 18902.62 | $4d\,^4G_{2\frac{1}{2}} - 4f\,^2F^\circ_{3\frac{1}{2}}$ |
| 5133.098 | 5 | 19475.99 | | 5298.909 | 25 | 18866.56 | $4d''\,^2P_{0\frac{1}{2}} - 4f''\,^4D^\circ_{1\frac{1}{2}}$ |
| 5134.285 | 60 | 19471.48 | $4d\,^4G_{4\frac{1}{2}} - 4f\,^4G^\circ_{4\frac{1}{2}}$ | 5302.404 | 5 | 18854.12 | $4d\,^2H_{4\frac{1}{2}} - 4f\,^4I^\circ_{5\frac{1}{2}}$ |
| 5136.828 | 80 | 19461.84 | $4d'\,^2D_{2\frac{1}{2}} - 4f'\,^2F^\circ_{3\frac{1}{2}}$ | 5306.464 | 2 | 18839.70 | |
| 5137.077 | 5 | 19460.90 | | 5307.169 | 1 | 18837.20 | $4d''\,^2P_{0\frac{1}{2}} - 6f\,^2P^\circ_{1\frac{1}{2}}$ |
| 5138.944 | 0 | 19453.83 | $4d\,^2G_{3\frac{1}{2}} - 4f\,^2F^\circ_{2\frac{1}{2}}$ | 5313.534 | 0 | 18814.63 | $4d''\,^2P_{1\frac{1}{2}} - 4f''\,^4D^\circ_{1\frac{1}{2}}$ |
| 5139.926 | 100 | 19450.11 | $4d\,^4G_{4\frac{1}{2}} - 4f\,^4H^\circ_{5\frac{1}{2}}$ | 5318.134 | 0 | 18798.36 | $4d\,^2P_{1\frac{1}{2}} - 4f\,^4P^\circ_{1\frac{1}{2}}$ |
| 5141.558 | 3 | 19443.94 | $4d''\,^4F_{2\frac{1}{2}} - 4f''\,^2F^\circ_{3\frac{1}{2}}$ | 5327.820 | 1 | 18764.18 | $4f\,^4I^\circ_{6\frac{1}{2}} - 7g\,^4K_{7\frac{1}{2}}$ |
| 5142.535 | 80 | 19440.25 | $4d\,^2G_{3\frac{1}{2}} - 4f\,^2H^\circ_{4\frac{1}{2}}$ | 5336.856 | 0 | 18732.41 | $4d''\,^4P_{2\frac{1}{2}} - 4f''\,^2G^\circ_{3\frac{1}{2}}$ |
| 5142.810 | 10 | 19439.21 | $4d'\,^2D_{2\frac{1}{2}} - 4f'\,^2G^\circ_{3\frac{1}{2}}$ | 5337.790 | 0 | 18729.14 | $4d''\,^4P_{2\frac{1}{2}} - 4f''\,^4F^\circ_{2\frac{1}{2}}$ |
| 5143.058 | 40 | 19438.27 | $4d\,^2G_{3\frac{1}{2}} - 4f\,^2G^\circ_{3\frac{1}{2}}$ | 5340.652 | 2 | 18719.10 | $4f\,^4I^\circ_{7\frac{1}{2}} - 7g\,^4K_{8\frac{1}{2}}$ |
| 5144.905 | 15 | 19431.29 | $4d\,^4G_{4\frac{1}{2}} - 4f\,^4D^\circ_{3\frac{1}{2}}$ | 5342.291 | 0 | 18713.36 | $4f\,^2I^\circ_{5\frac{1}{2}} - 7g\,^2K_{6\frac{1}{2}}$ |
| 5145.343 | 20 | 19429.64 | | 5342.664 | 5 | 18712.05 | $4d''\,^4P_{2\frac{1}{2}} - 4f''\,^4F^\circ_{3\frac{1}{2}}$ |
| 5149.719 | 60 | 19413.13 | $4d''\,^2F_{3\frac{1}{2}} - 4f''\,^4G^\circ_{4\frac{1}{2}}$ | 5343.112 | 0 | 18710.48 | $4f\,^2I^\circ_{6\frac{1}{2}} - 7g\,^2K_{7\frac{1}{2}}$ |
| 5150.898 | 20 | 19408.68 | $4d''\,^4P_{0\frac{1}{2}} - 4f''\,^4D^\circ_{0\frac{1}{2}}$ | 5344.144 | 5 | 18706.87 | $4d''\,^2P_{0\frac{1}{2}} - 4f''\,^4F^\circ_{1\frac{1}{2}}$ |
| 5155.550 | 10 | 19391.17 | $4d''\,^4P_{0\frac{1}{2}} - 4f''\,^4D^\circ_{1\frac{1}{2}}$ | 5347.256 | 0 | 18695.98 | $4d\,^2P_{1\frac{1}{2}} - 4f\,^2S^\circ_{0\frac{1}{2}}$ |
| 5155.839 | 30 | 19390.08 | $4d''\,^4P_{2\frac{1}{2}} - 4f''\,^2F^\circ_{2\frac{1}{2}}$ | 5351.773 | 1 | 18680.20 | $4f\,^4H^\circ_{5\frac{1}{2}} - 7g\,^4H_{5\frac{1}{2}}$ |
| 5157.162 | 10 | 19385.11 | $4d\,^2G_{3\frac{1}{2}} - 4f\,^4I^\circ_{4\frac{1}{2}}$ | 5351.847 | 2 | 18679.94 | $4f\,^4H^\circ_{6\frac{1}{2}} - 7g\,^4H_{6\frac{1}{2}}$ |
| 5158.243 | 10 | 19381.05 | $4d''\,^2D_{1\frac{1}{2}} - 4f''\,^4D^\circ_{2\frac{1}{2}}$ | 5353.372 | 40 | 18674.62 | $4d''\,^2P_{1\frac{1}{2}} - 4f''\,^2D^\circ_{2\frac{1}{2}}$ |
| 5158.962 | 20 | 19378.35 | $4d'\,^2S_{0\frac{1}{2}} - 4f'\,^2P^\circ_{0\frac{1}{2}}$ | 5355.219 | 1 | 18668.18 | $4d''\,^4P_{2\frac{1}{2}} - 4f''\,^2F^\circ_{3\frac{1}{2}}$ |
| 5160.008 | 8 | 19374.42 | | 5359.013 | 3 | 18654.96 | $4d''\,^2P_{1\frac{1}{2}} - 4f''\,^4F^\circ_{1\frac{1}{2}}$ |
| 5162.824 | 20 | 19363.85 | $4d\,^4D_{2\frac{1}{2}} - 4f\,^4F^\circ_{3\frac{1}{2}}$ | 5364.579 | 1 | 18635.61 | $4f\,^4G^\circ_{5\frac{1}{2}} - 7g\,^4G_{5\frac{1}{2}}$ |
| 5164.012 | 40 | 19359.40 | $4d'\,^2S_{0\frac{1}{2}} - 4f'\,^2P^\circ_{1\frac{1}{2}}$ | 5368.135 | 30 | 18623.26 | $4d''\,^2P_{1\frac{1}{2}} - 4f''\,^4F^\circ_{2\frac{1}{2}}$ |
| 5164.343 | 2 | 19358.16 | $4d''\,^4P_{0\frac{1}{2}} - 6f\,^4D^\circ_{1\frac{1}{2}}$ | 5375.204 | 3 | 18598.77 | |
| | | | $4d''\,^4P_{1\frac{1}{2}} - 4f''\,^4D^\circ_{0\frac{1}{2}}$ | 5375.931 | 3 | 18596.26 | |
| 5169.022 | 10 | 19340.63 | $4d''\,^4P_{1\frac{1}{2}} - 4f''\,^4D^\circ_{1\frac{1}{2}}$ | 5386.189 | 3 | 18560.84 | $4d\,^4H_{4\frac{1}{2}} - 4f\,^4H^\circ_{5\frac{1}{2}}$ |
| 5169.564 | 30 | 19338.60 | $4d\,^4D_{2\frac{1}{2}} - 4f\,^4D^\circ_{2\frac{1}{2}}$ | 5394.085 | 5 | 18533.67 | $4d\,^4F_{2\frac{1}{2}} - 4f\,^4F^\circ_{3\frac{1}{2}}$ |
| 5173.065 | 5 | 19325.52 | $4d''\,^4F_{1\frac{1}{2}} - 4f''\,^4F^\circ_{1\frac{1}{2}}$ | | | | $6s\,^4F_{4\frac{1}{2}} - 8p\,^4G^\circ_{5\frac{1}{2}}$ |
| 5173.976 | 3 | 19322.11 | $4d'\,^2D_{2\frac{1}{2}} - 4f'\,^2F^\circ_{2\frac{1}{2}}$ | 5394.498 | 15 | 18532.25 | $4d\,^4F_{3\frac{1}{2}} - 5p'\,^2D^\circ_{2\frac{1}{2}}$ |
| 5174.155 | 5 | 19321.45 | $4d''\,^2F_{2\frac{1}{2}} - 4f''\,^2D^\circ_{2\frac{1}{2}}$ | | | | $4d\,^2G_{3\frac{1}{2}} - 4f\,^4H^\circ_{4\frac{1}{2}}$ |
| 5174.775 | 3 | 19319.13 | $4d''\,^2F_{3\frac{1}{2}} - 4f''\,^2G^\circ_{3\frac{1}{2}}$ | 5401.445 | 5 | 18508.42 | $4d\,^4F_{2\frac{1}{2}} - 4f\,^4D^\circ_{2\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 5405.513 | 3 | 18494.49 | $4d\,^2H_{5\frac{1}{2}} - 4f\,^4I^\circ_{6\frac{1}{2}}$ |
| 5470.824 | 5 | 18273.70 | $4d\,^2G_{4\frac{1}{2}} - 4f\,^4H^\circ_{5\frac{1}{2}}$ |
| 5502.486 | 3 | 18168.56 | $4d\,^2D_{2\frac{1}{2}} - 4f\,^2F^\circ_{2\frac{1}{2}}$ |
| 5507.214 | 30 | 18152.96 | $4d\,^2D_{2\frac{1}{2}} - 4f\,^2G^\circ_{3\frac{1}{2}}$ |
| 5516.811 | 3 | 18121.38 | $4d\,^2D_{2\frac{1}{2}} - 4f\,^4G^\circ_{2\frac{1}{2}}$ |
| 5588.975 | 15 | 17887.40 | |
| 5633.532 | 2 | 17745.93 | $5d\,^4H_{6\frac{1}{2}} - 7f\,^4I^\circ_{7\frac{1}{2}}$ |
| 5655.744 | 1 | 17676.23 | |
| 5702.726 | 5 | 17530.61 | $4d\,^2D_{1\frac{1}{2}} - 4f\,^2F^\circ_{2\frac{1}{2}}$ |
| 5713.523 | 3 | 17497.48 | |
| 5718.117 | 10 | 17483.42 | $4d\,^2D_{1\frac{1}{2}} - 4f\,^4G^\circ_{2\frac{1}{2}}$ |
| 5741.882 | 3 | 17411.06 | |
| 5752.486 | 3 | 17378.97 | $4d\,^2D_{1\frac{1}{2}} - 4f\,^2D^\circ_{1\frac{1}{2}}$ |
| 5765.246 | 5 | 17340.50 | |
| 5769.015 | 0 | 17329.18 | $5p\,^4G^\circ_{5\frac{1}{2}} - 4d'''\,^2I_{6\frac{1}{2}}$? |
| 5773.635 | 1h | 17315.31 | |
| 5796.702 | 10 | 17246.41 | $4d\,^2D_{2\frac{1}{2}} - 4f\,^2D^\circ_{2\frac{1}{2}}$ |
| 5797.761 | 20 | 17243.26 | $4d\,^2D_{2\frac{1}{2}} - 4f\,^2F^\circ_{3\frac{1}{2}}$ |
| 5814.001 | 5 | 17195.09 | $4p\,^4G^\circ_{3\frac{1}{2}} - s^2\,^2G_{3\frac{1}{2}}$ |
| 5819.821 | 1 | 17177.90 | $4d\,^2D_{2\frac{1}{2}} - 4f\,^4F^\circ_{2\frac{1}{2}}$ |
| 5820.908 | 1 | 17174.69 | |
| 5821.290 | 1 | 17173.56 | $4d\,^2D_{2\frac{1}{2}} - 4f\,^2P^\circ_{1\frac{1}{2}}$ |
| 5882.812 | 10? | 16993.96 | $4p\,^4G^\circ_{4\frac{1}{2}} - s^2\,^2G_{4\frac{1}{2}}$ |
| 6037.275 | 3h | 16559.18 | $4d\,^2D_{1\frac{1}{2}} - 4f\,^4D^\circ_{1\frac{1}{2}}$ |
| 6040.924 | 2 | 16549.18 | |
| 6044.315 | 1 | 16539.89 | $4d\,^2D_{1\frac{1}{2}} - 4f\,^4F^\circ_{2\frac{1}{2}}$ |
| 6045.860 | 1 | 16535.67 | $4d\,^2D_{1\frac{1}{2}} - 4f\,^2P^\circ_{1\frac{1}{2}}$ |
| | | | $5p'\,^2P^\circ_{1\frac{1}{2}} - 7d\,^4D_{2\frac{1}{2}}$ |
| 6048.768 | 1 | 16527.72 | |
| 6062.008 | 3 | 16491.62 | $5p''\,^4P^\circ_{2\frac{1}{2}} - 5d''\,^4D_{2\frac{1}{2}}$ |
| 6068.641 | 20 | 16473.59 | $4p\,^2D^\circ_{2\frac{1}{2}} - s^2\,^2P_{1\frac{1}{2}}$ |
| 6094.190 | 20 | 16404.53 | $5p''\,^4P^\circ_{2\frac{1}{2}} - 5d''\,^4D_{3\frac{1}{2}}$ |
| 6124.910 | 50 | 16322.25 | $4p\,^4D^\circ_{3\frac{1}{2}} - s^2\,^4P_{2\frac{1}{2}}$ |
| 6137.382 | 0 | 16289.08 | $5p'\,^2D^\circ_{1\frac{1}{2}} - 5d'\,^2D_{2\frac{1}{2}}$ |
| 6148.256 | 5 | 16260.27 | $5p\,^4D^\circ_{3\frac{1}{2}} - 5d\,^4F_{4\frac{1}{2}}$ |
| 6148.674 | 2 | 16259.17 | $5p\,^4D^\circ_{1\frac{1}{2}} - 5d\,^4D_{1\frac{1}{2}}$ |
| 6155.711 | 1h | 16240.58 | |
| 6158.188 | 1 | 16234.05 | |
| 6173.036 | 5 | 16195.00 | $5p'\,^2D^\circ_{2\frac{1}{2}} - 5d'\,^2P_{1\frac{1}{2}}$ |
| 6173.377 | 3h | 16194.11 | |
| 6174.596 | 0 | 16190.91 | $5p'\,^2D^\circ_{1\frac{1}{2}} - 5d'\,^2P_{0\frac{1}{2}}$ |
| 6178.653 | 10 | 16180.28 | $5p'\,^2D^\circ_{2\frac{1}{2}} - 5d'\,^2D_{2\frac{1}{2}}$ |
| 6194.433 | 3 | 16139.06 | $5p'\,^2D^\circ_{1\frac{1}{2}} - 5d'\,^2D_{1\frac{1}{2}}$ |
| 6199.957 | 5 | 16124.68 | |
| 6200.959 | 5 | 16122.08 | $5p''\,^4P^\circ_{1\frac{1}{2}} - 5d''\,^4D_{2\frac{1}{2}}$ |
| 6210.132 | 2 | 16098.26 | $5p'\,^2D^\circ_{1\frac{1}{2}} - 6s''\,^2P_{1\frac{1}{2}}$ |
| 6219.909 | 3 | 16072.96 | |
| 6224.134 | 3 | 16062.05 | $5p\,^4D^\circ_{0\frac{1}{2}} - 5d\,^4F_{1\frac{1}{2}}$ |
| 6236.492 | 2 | 16030.22 | $5p\,^4F^\circ_{2\frac{1}{2}} - 5d\,^4D_{1\frac{1}{2}}$ |
| | | | $5p'\,^2D^\circ_{2\frac{1}{2}} - 5d'\,^2D_{1\frac{1}{2}}$ |
| 6243.486 | 40 | 16012.26 | $5p\,^4D^\circ_{3\frac{1}{2}} - 5d\,^4P_{2\frac{1}{2}}$ |
| 6243.775 | 2 | 16011.52 | $5p''\,^4P^\circ_{0\frac{1}{2}} - 5d''\,^4D_{1\frac{1}{2}}$ |
| 6247.024 | 30 | 16003.20 | $5p\,^4D^\circ_{3\frac{1}{2}} - 5d\,^4D_{3\frac{1}{2}}$ |
| 6259.467 | 10 | 15971.38 | $5p'\,^2D^\circ_{1\frac{1}{2}} - 5d'\,^2F_{2\frac{1}{2}}$ |
| | | | $4p'''\,^2F^\circ_{2\frac{1}{2}} - s^2\,^2F_{2\frac{1}{2}}$ |
| 6272.945 | 30 | 15937.07 | $5p'\,^2D^\circ_{2\frac{1}{2}} - 8s\,^4F_{3\frac{1}{2}}$ |
| 6278.953 | 1 | 15921.82 | $5p\,^4F^\circ_{4\frac{1}{2}} - 5d\,^4F_{3\frac{1}{2}}$ |
| 6286.633 | 5 | 15902.37 | $5p\,^4D^\circ_{0\frac{1}{2}} - 5d\,^4D_{0\frac{1}{2}}$ |
| 6288.500 | 10 | 15897.65 | $5p\,^4G^\circ_{5\frac{1}{2}} - 5d\,^4G_{4\frac{1}{2}}$ |
| | | | $4d\,^2D_{2\frac{1}{2}} - 4f\,^4F^\circ_{3\frac{1}{2}}$ |
| 6298.502 | 15 | 15872.40 | $4d\,^2D_{2\frac{1}{2}} - 4f\,^4D^\circ_{2\frac{1}{2}}$ |
| 6302.417 | 40 | 15862.54 | $5p'\,^2D^\circ_{2\frac{1}{2}} - 5d'\,^2F_{2\frac{1}{2}}$ |
| 6302.532 | 75 | 15862.25 | $5p'\,^2D^\circ_{2\frac{1}{2}} - 5d'\,^2F_{3\frac{1}{2}}$ |
| 6302.699 | 3 | 15861.83 | $5p\,^4G^\circ_{2\frac{1}{2}} - 5d\,^4G_{2\frac{1}{2}}$ |
| 6314.457 | 40 | 15832.30 | $5p\,^4F^\circ_{4\frac{1}{2}} - 5d\,^4F_{4\frac{1}{2}}$ |
| 6319.828 | 15 | 15818.84 | $5p\,^4G^\circ_{3\frac{1}{2}} - 5d\,^4G_{3\frac{1}{2}}$ |
| 6326.641 | 5 | 15801.81 | $4p\,^4F_{4\frac{1}{2}} - s^2\,^2G_{4\frac{1}{2}}$ |
| 6332.209 | 3 | 15787.91 | $5p\,^4D^\circ_{1\frac{1}{2}} - 5d\,^4F_{2\frac{1}{2}}$ |
| 6337.120 | 20 | 15775.68 | $5p\,^4F^\circ_{1\frac{1}{2}} - 5d\,^4G_{2\frac{1}{2}}$ |
| 6341.012 | 3 | 15765.99 | $5p\,^4G^\circ_{5\frac{1}{2}} - 5d\,^4F_{4\frac{1}{2}}$ |
| 6341.761 | 50 | 15764.13 | $5p\,^4G^\circ_{2\frac{1}{2}} - 5d\,^4H_{3\frac{1}{2}}$ |
| 6346.657 | 75 | 15751.97 | $5p\,^4F^\circ_{4\frac{1}{2}} - 5d\,^4H_{5\frac{1}{2}}$ |
| 6348.783 | 40 | 15746.70 | $5p\,^4G^\circ_{4\frac{1}{2}} - 5d\,^4G_{4\frac{1}{2}}$ |
| 6350.621 | 20 | 15742.14 | $5p\,^4G^\circ_{5\frac{1}{2}} - 5d\,^4G_{5\frac{1}{2}}$ |
| 6361.388 | 10 | 15715.49 | $5p\,^4F^\circ_{1\frac{1}{2}} - 5d\,^4F_{1\frac{1}{2}}$ |
| 6365.320 | 30 | 15705.79 | $5p\,^2G^\circ_{4\frac{1}{2}} - 5d\,^2G_{4\frac{1}{2}}$ |
| 6371.200 | 75 | 15691.29 | $5p\,^4G^\circ_{3\frac{1}{2}} - 5d\,^4H_{4\frac{1}{2}}$ |
| 6373.474 | 30 | 15685.69 | $5p\,^4G^\circ_{5\frac{1}{2}} - 5d\,^4H_{5\frac{1}{2}}$ |
| 6379.028 | 10 | 15672.04 | $5p\,^4D^\circ_{1\frac{1}{2}} - 5d\,^4P_{0\frac{1}{2}}$ |
| 6388.193 | 10 | 15649.55 | $5p\,^2G^\circ_{3\frac{1}{2}} - 5d\,^2G_{3\frac{1}{2}}$ |
| 6388.255 | 3 | 15649.40 | |
| 6388.374 | 30 | 15649.11 | $5p\,^4F^\circ_{2\frac{1}{2}} - 5d\,^4G_{3\frac{1}{2}}$ |
| 6391.707 | 20 | 15640.95 | $5p\,^4D^\circ_{2\frac{1}{2}} - 5d\,^4D_{2\frac{1}{2}}$ |
| 6397.694 | 150 | 15626.31 | $5p\,^4G^\circ_{5\frac{1}{2}} - 5d\,^4H_{6\frac{1}{2}}$ |
| 6398.162 | 5 | 15625.17 | |
| 6398.206 | 30 | 15625.06 | $5p'\,^2P^\circ_{1\frac{1}{2}} - 5d'\,^2P_{1\frac{1}{2}}$ |
| 6401.460 | 5 | 15617.12 | |
| 6401.920 | 50 | 15616.00 | $5p''\,^4D^\circ_{3\frac{1}{2}} - 5d''\,^4F_{4\frac{1}{2}}$ |
| 6402.246 | 30 | 15615.20 | $5p\,^4G^\circ_{4\frac{1}{2}} - 5d\,^4F_{4\frac{1}{2}}$ |
| | | | $5d\,^4F_{3\frac{1}{2}} - 6f\,^4F^\circ_{2\frac{1}{2}}$ |
| 6402.709 | 5 | 15614.07 | |
| 6404.258 | 30 | 15610.30 | $5p'\,^2P^\circ_{1\frac{1}{2}} - 5d'\,^2D_{2\frac{1}{2}}$ |
| 6411.571 | 3 | 15592.49 | |
| 6411.913 | 80 | 15591.66 | $5p\,^2G^\circ_{4\frac{1}{2}} - 5d\,^2H_{5\frac{1}{2}}$ |
| 6412.069 | 60 | 15591.28 | $5p\,^4G^\circ_{4\frac{1}{2}} - 5d\,^4G_{5\frac{1}{2}}$ |
| 6418.674 | 20 | 15575.24 | $5p\,^4F^\circ_{4\frac{1}{2}} - 5d\,^4D_{3\frac{1}{2}}$ |
| 6418.782 | 20 | 15574.97 | $5p''\,^4D^\circ_{1\frac{1}{2}} - 5d''\,^4P_{2\frac{1}{2}}$ |
| 6419.961 | 1 | 15572.11 | $5p\,^4F^\circ_{2\frac{1}{2}} - 5d\,^2F_{3\frac{1}{2}}$ |
| 6425.366 | 40 | 15559.02 | $5p\,^4F^\circ_{2\frac{1}{2}} - 5d\,^4F_{2\frac{1}{2}}$ |
| 6426.130 | 2 | 15557.17 | |
| 6426.669 | 2 | 15555.86 | $5p\,^4F^\circ_{1\frac{1}{2}} - 5d\,^4D_{0\frac{1}{2}}$ |
| 6428.869 | 100 | 15550.54 | $5p'\,^2F^\circ_{2\frac{1}{2}} - 5d'\,^2G_{3\frac{1}{2}}$? |
| 6429.817 | 5 | 15548.24 | |
| 6433.786 | 60 | 15538.65 | $5p''\,^4D^\circ_{2\frac{1}{2}} - 5d''\,^4F_{3\frac{1}{2}}$ |
| 6435.364 | 5 | 15534.84 | $5p\,^4G^\circ_{4\frac{1}{2}} - 5d\,^4H_{5\frac{1}{2}}$ |
| 6437.533 | 2 | 15529.61 | $4f\,^4I^\circ_{6\frac{1}{2}} - 6g\,^4H_{5\frac{1}{2}}$ |
| 6440.970 | 20 | 15521.32 | $4f\,^4I^\circ_{6\frac{1}{2}} - 6g\,^4K_{7\frac{1}{2}}$ |
| 6441.099 | 10 | 15521.01 | $5d\,^4F_{4\frac{1}{2}} - 4f'''\,^4F^\circ_{4\frac{1}{2}}$ |
| 6441.426 | 75 | 15520.22 | $5p\,^2G^\circ_{3\frac{1}{2}} - 5d\,^2H_{4\frac{1}{2}}$ |
| 6443.163 | 2 | 15516.04 | |
| 6445.111 | 5 | 15511.35 | |
| 6447.322 | 3 | 15506.03 | |
| 6447.583 | 20 | 15505.40 | |
| 6447.998 | 20 | 15504.40 | $5p''\,^4S^\circ_{1\frac{1}{2}} - 5d''\,^4P_{2\frac{1}{2}}$ |
| 6449.266 | 2 | 15501.36 | |
| 6449.958 | 10 | 15499.69 | $5p\,^4D^\circ_{2\frac{1}{2}} - 5d\,^4F_{3\frac{1}{2}}$ |
| 6450.280 | 3 | 15498.92 | $4f\,^4P^\circ_{2\frac{1}{2}} - 5g\,^4D_{3\frac{1}{2}}$ |
| 6450.676 | 2 | 15497.97 | |
| 6450.818 | 5 | 15497.63 | $5p\,^4F^\circ_{3\frac{1}{2}} - 5d\,^4D_{2\frac{1}{2}}$ |
| 6451.544 | 1 | 15495.88 | |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 6451.805 | 5 | 15495.26 | $4f\ ^4P^\circ_{2\frac{1}{2}} - 6g\ ^4P_{2\frac{1}{2}}$ |
| 6452.844 | 2 | 15492.76 | $4d''\ ^4P_{2\frac{1}{2}} - v\ ^4P^\circ_{1\frac{1}{2}}$ |
| 6455.543 | 2 | 15486.28 | |
| 6455.671 | 5 | 15485.98 | |
| 6456.301 | 5 | 15484.47 | $4f\ ^4I^\circ_{7\frac{1}{2}} - 6g\ ^4H_{6\frac{1}{2}}$ |
| 6457.032 | 1 | 15482.71 | |
| 6457.223 | 1 | 15482.25 | $4f\ ^4I^\circ_{5\frac{1}{2}} - 6g\ ^4H_{4\frac{1}{2}}$ |
| 6457.347 | 2 | 15481.96 | |
| 6458.217 | 5 | 15479.87 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 5d\ ^4G_{3\frac{1}{2}}$ |
| 6458.949 | 1 | 15478.12 | |
| 6459.735 | 100 | 15476.23 | $4f\ ^4I^\circ_{7\frac{1}{2}} - 6g\ ^4K_{8\frac{1}{2}}$ |
| 6459.937 | 1 | 15475.75 | $4d\ ^4D_{2\frac{1}{2}} - 6f\ ^4D^\circ_{1\frac{1}{2}}$ |
| 6460.103 | 60 | 15475.35 | $4f\ ^4I^\circ_{5\frac{1}{2}} - 6g\ ^4K_{6\frac{1}{2}}$ |
| | | | $4f\ ^2I^\circ_{6\frac{1}{2}} - 6g\ ^2H_{5\frac{1}{2}}$ |
| 6460.182 | 40 | 15475.16 | $4f\ ^2I^\circ_{5\frac{1}{2}} - 6g\ ^2K_{6\frac{1}{2}}$ |
| 6462.072 | 20 | 15470.64 | $4f\ ^4I^\circ_{4\frac{1}{2}} - 6g\ ^4K_{5\frac{1}{2}}$ |
| 6463.008 | 60 | 15468.40 | $4f\ ^2I^\circ_{6\frac{1}{2}} - 6g\ ^2K_{7\frac{1}{2}}$ |
| 6463.736 | 2 | 15466.65 | $5p''\ ^4D^\circ_{1\frac{1}{2}} - 7d\ ^4F_{1\frac{1}{2}}$ |
| 6465.439 | 1 | 15462.58 | $4f\ ^4D^\circ_{3\frac{1}{2}} - 6g\ ^4G_{4\frac{1}{2}}$ |
| 6466.754 | 8 | 15459.44 | |
| 6467.472 | 10 | 15457.72 | $4f\ ^4D^\circ_{3\frac{1}{2}} - 6g\ ^4F_{4\frac{1}{2}}$ |
| 6467.923 | 75 | 15456.64 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 5d\ ^2G_{4\frac{1}{2}}$ |
| 6468.835 | 15 | 15454.46 | |
| 6469.263 | 8 | 15453.44 | $4f\ ^4D^\circ_{3\frac{1}{2}} - 6g\ ^4D_{3\frac{1}{2}}$ |
| 6470.107 | 10 | 15451.43 | |
| 6470.486 | 1 | 15450.52 | $4f\ ^4P^\circ_{1\frac{1}{2}} - 6g\ ^4D_{2\frac{1}{2}}$ |
| 6470.796 | 1 | 15449.78 | $4f\ ^4D^\circ_{3\frac{1}{2}} - 6g\ ^4P_{2\frac{1}{2}}$ |
| 6472.044 | 5 | 15446.80 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 5d\ ^2P_{1\frac{1}{2}}$ |
| | | | $4f\ ^4P^\circ_{1\frac{1}{2}} - 6g\ ^4P_{1\frac{1}{2}}$ |
| 6473.341 | 5 | 15443.71 | $4f\ ^4H^\circ_{5\frac{1}{2}} - 6g\ ^4G_{4\frac{1}{2}}$ |
| 6473.457 | 5h | 15443.43 | $4f\ ^4H^\circ_{6\frac{1}{2}} - 6g\ ^4G_{5\frac{1}{2}}$ |
| | | | $4f\ ^4G^\circ_{3\frac{1}{2}} - 6g\ ^4H_{4\frac{1}{2}}$ |
| 6473.523 | 20h | 15443.27 | $4f\ ^4G^\circ_{3\frac{1}{2}} - 6g\ ^4F_{2\frac{1}{2}}$ |
| 6473.625 | 5 | 15443.03 | $5p''\ ^4S^\circ_{1\frac{1}{2}} - 5d''\ ^4P_{1\frac{1}{2}}$ |
| 6474.717 | 40 | 15440.42 | $4f\ ^4H^\circ_{5\frac{1}{2}} - 6g\ ^4H_{5\frac{1}{2}}$ |
| 6474.821 | 60 | 15440.18 | $4f\ ^4H^\circ_{6\frac{1}{2}} - 6g\ ^4H_{6\frac{1}{2}}$ |
| 6475.175 | 3 | 15439.33 | |
| 6476.357 | 2h | 15436.51 | |
| 6477.429 | 5 | 15433.96 | $4f\ ^4D^\circ_{2\frac{1}{2}} - 6g\ ^4F_{3\frac{1}{2}}$ |
| 6479.234 | 4 | 15429.66 | $4f\ ^4D^\circ_{2\frac{1}{2}} - 6g\ ^4D_{2\frac{1}{2}}$ |
| 6480.420 | 10 | 15426.84 | $5p\ ^2G^\circ_{3\frac{1}{2}} - 5d\ ^4H_{3\frac{1}{2}}$ |
| | | | $4f\ ^2F^\circ_{3\frac{1}{2}} - 6g\ ^2G_{4\frac{1}{2}}$ |
| 6480.811 | 2h | 15425.90 | $4f\ ^4D^\circ_{2\frac{1}{2}} - 6g\ ^4P_{1\frac{1}{2}}$ |
| 6480.976 | 8 | 15425.51 | |
| 6481.120 | 2 | 15425.17 | $4f\ ^2H^\circ_{5\frac{1}{2}} - 6g\ ^2G_{4\frac{1}{2}}$ |
| 6481.344 | 4h | 15424.64 | $4f\ ^2F^\circ_{3\frac{1}{2}} - 6g\ ^2F_{3\frac{1}{2}}$ |
| 6481.669 | 20 | 15423.86 | $4f\ ^4H^\circ_{5\frac{1}{2}} - 6g\ ^4I_{6\frac{1}{2}}$ |
| 6481.797 | 40 | 15423.56 | $4f\ ^4H^\circ_{6\frac{1}{2}} - 6g\ ^4I_{7\frac{1}{2}}$ |
| 6481.972 | 2 | 15423.14 | $4f\ ^2H^\circ_{5\frac{1}{2}} - 6g\ ^2H_{5\frac{1}{2}}$ |
| | | | $4f\ ^4H^\circ_{4\frac{1}{2}} - 6g\ ^2G_{4\frac{1}{2}}$ |
| 6482.308 | 5 | 15422.34 | $4f\ ^4G^\circ_{4\frac{1}{2}} - 6g\ ^4G_{4\frac{1}{2}}$ |
| 6482.659 | 30h | 15421.51 | $4f\ ^2D^\circ_{2\frac{1}{2}} - 6g\ ^2F_{3\frac{1}{2}}$ |
| 6483.539 | 2 | 15419.41 | $5d\ ^4P_{0\frac{1}{2}} - 6f\ ^4F^\circ_{1\frac{1}{2}}$ |
| | | | $5p'\ ^2P^\circ_{1\frac{1}{2}} - 6s''\ ^2P_{1\frac{1}{2}}$ |
| 6483.868 | 5 | 15418.63 | |
| 6484.056 | 40 | 15418.18 | $4f\ ^2H^\circ_{4\frac{1}{2}} - 6g\ ^2I_{5\frac{1}{2}}$ |
| 6484.083 | 10 | 15418.12 | $4p\ ^4D^\circ_{2\frac{1}{2}} - s^2\ ^4P_{1\frac{1}{2}}$ |
| 6484.347 | 10 | 15417.49 | $4f\ ^4G^\circ_{4\frac{1}{2}} - 6g\ ^4F_{3\frac{1}{2}}$ |
| 6485.584 | 15 | 15414.55 | $4f\ ^2G^\circ_{4\frac{1}{2}} - 6g\ ^2G_{4\frac{1}{2}}$ |
| 6486.523 | 15 | 15412.32 | $4f\ ^2G^\circ_{4\frac{1}{2}} - 6g\ ^2F_{3\frac{1}{2}}$ |
| 6486.616 | 5 | 15412.10 | |
| 6486.768 | 1 | 15411.74 | |
| 6486.817 | 1 | 15411.62 | $5p''\ ^2D^\circ_{1\frac{1}{2}} - 5d''\ ^2P_{0\frac{1}{2}}$ |
| 6487.539 | 5 | 15409.91 | |
| 6487.634 | 10 | 15409.68 | $4f\ ^4F^\circ_{4\frac{1}{2}} - 6g\ ^4G_{5\frac{1}{2}}$ |
| 6488.058 | 4 | 15408.67 | $4f\ ^4F^\circ_{3\frac{1}{2}} - 6g\ ^4F_{3\frac{1}{2}}$ |
| 6488.128 | 10 | 15408.51 | |
| 6488.452 | 50 | 15407.74 | $4f\ ^2H^\circ_{5\frac{1}{2}} - 6g\ ^2I_{6\frac{1}{2}}$ |
| 6488.971 | 20 | 15406.51 | $5p\ ^4D^\circ_{2\frac{1}{2}} - 5d\ ^4P_{1\frac{1}{2}}$ |
| 6489.684 | 3 | 15404.81 | $4f\ ^4F^\circ_{4\frac{1}{2}} - 6g\ ^4F_{4\frac{1}{2}}$ |
| 6490.509 | 25 | 15402.86 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 5d\ ^2F_{3\frac{1}{2}}$ |
| 6491.481 | 2h | 15400.55 | $4f\ ^4F^\circ_{4\frac{1}{2}} - 6g\ ^4D_{3\frac{1}{2}}$ |
| | | | $4p\ ^2F^\circ_{2\frac{1}{2}} - s^2\ ^2P_{1\frac{1}{2}}$ |
| 6492.379 | 40 | 15398.42 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 5d\ ^4G_{4\frac{1}{2}}$ |
| 6492.934 | 20 | 15397.10 | $4f\ ^4G^\circ_{5\frac{1}{2}} - 6g\ ^4G_{5\frac{1}{2}}$ |
| 6493.437 | 8 | 15395.91 | $4d'\ ^2D_{2\frac{1}{2}} - 5f\ ^4P^\circ_{2\frac{1}{2}}$ |
| 6497.913 | 1h | 15385.31 | $5p''\ ^4D^\circ_{3\frac{1}{2}} - 5d''\ ^4D_{2\frac{1}{2}}$ |
| 6499.074 | 2h | 15382.56 | $4p\ ^4F^\circ_{2\frac{1}{2}} - s^2\ ^2G_{3\frac{1}{2}}$ |
| 6499.860 | 20 | 15380.70 | $5p''\ ^4D^\circ_{1\frac{1}{2}} - 5d''\ ^4F_{2\frac{1}{2}}$ |
| 6500.283 | 15 | 15379.70 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 5d\ ^2F_{3\frac{1}{2}}$ |
| 6502.317 | 75 | 15374.89 | |
| 6508.607 | 100 | 15360.03 | |
| 6509.452 | 3 | 15358.03 | $5p\ ^4G^\circ_{4\frac{1}{2}} - 5d\ ^4D_{3\frac{1}{2}}$ |
| 6510.169 | 30 | 15356.34 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 5d\ ^4F_{3\frac{1}{2}}$ |
| 6510.371 | 2h | 15355.86 | $5p'\ ^2F^\circ_{2\frac{1}{2}} - 5d'\ ^2F_{3\frac{1}{2}}$ |
| 6524.833 | 2h | 15321.83 | |
| 6534.903 | 10 | 15298.22 | $5p''\ ^4D^\circ_{3\frac{1}{2}} - 5d''\ ^4D_{3\frac{1}{2}}$ |
| 6541.396 | 1h | 15283.03 | |
| 6541.858 | 1h | 15281.96 | |
| 6546.986 | 1h | 15269.99 | |
| 6547.270 | 2h | 15269.32 | |
| 6548.339 | 2 | 15266.83 | $5p\ ^4F^\circ_{3\frac{1}{2}} - 5d\ ^4F_{4\frac{1}{2}}$ |
| 6553.677 | 5 | 15254.40 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 5d\ ^4P_{1\frac{1}{2}}$ |
| 6557.122 | 10 | 15246.38 | $5p'\ ^2F^\circ_{3\frac{1}{2}} - 8s\ ^4F_{3\frac{1}{2}}$ |
| 6570.916 | 3 | 15214.38 | |
| 6572.648 | 2 | 15210.37 | |
| 6580.931 | 3 | 15191.22 | |
| 6582.377 | 20 | 15187.89 | $5p\ ^2F^\circ_{2\frac{1}{2}} - 5d\ ^2G_{3\frac{1}{2}}$ |
| 6589.340 | 4 | 15171.84 | $5p'\ ^2F^\circ_{3\frac{1}{2}} - 5d'\ ^2F_{2\frac{1}{2}}$ |
| 6589.457 | 20 | 15171.57 | $5p'\ ^2F^\circ_{3\frac{1}{2}} - 5d'\ ^2F_{3\frac{1}{2}}$ |
| | | | $5p''\ ^4D^\circ_{0\frac{1}{2}} - 5d''\ ^4F_{1\frac{1}{2}}$ |
| 6590.259 | 4 | 15169.72 | |
| 6594.779 | 4 | 15159.32 | |
| 6602.461 | 10 | 15141.69 | $4p\ ^4D^\circ_{2\frac{1}{2}} - s^2\ ^4P_{2\frac{1}{2}}$ |
| 6603.496 | 2 | 15139.31 | |
| 6626.687 | 50 | 15086.33 | $4p\ ^2G^\circ_{3\frac{1}{2}} - s^2\ ^2G_{3\frac{1}{2}}$ |
| 6630.191 | 10 | 15078.36 | |
| 6631.637 | 10 | 15075.07 | $4p\ ^4D^\circ_{1\frac{1}{2}} - s^2\ ^4P_{0\frac{1}{2}}$ |
| 6634.702 | 1h | 15068.11 | |
| 6638.651 | 20 | 15059.14 | $4p\ ^2G^\circ_{4\frac{1}{2}} - s^2\ ^2G_{4\frac{1}{2}}$ |
| 6647.893 | 2 | 15038.21 | |
| 6665.713 | 5 | 14998.00 | $5p\ ^2F^\circ_{2\frac{1}{2}} - 4d'''\ ^2F_{2\frac{1}{2}}$ |
| 6691.092 | 3 | 14941.12 | $4p\ ^4F^\circ_{3\frac{1}{2}} - s^2\ ^2G_{4\frac{1}{2}}$ |
| 6692.432 | 2 | 14938.13 | $5p\ ^2D^\circ_{1\frac{1}{2}} - 4d'''\ ^2F_{2\frac{1}{2}}$ |
| 6702.123 | 2 | 14916.53 | |
| 6705.406 | 1 | 14909.22 | $5s'\ ^2D_{1\frac{1}{2}} - 5p''\ ^2P^\circ_{1\frac{1}{2}}$ |
| 6713.493 | 2 | 14891.26 | |
| 6735.74 | 1 | 14842.08 | $w\ ^4D^\circ_{3\frac{1}{2}} - 6d\ ^4D_{2\frac{1}{2}}$ |
| 6738.75 | 1 | 14835.45 | |
| 6740.20 | 2 | 14832.26 | $5d\ ^4D_{1\frac{1}{2}} - 6f\ ^4F^\circ_{1\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 6839.57 | 1 | 14616.77 | $5p\ ^2F^\circ_{2\frac{1}{2}} - 5d\ ^4D_{1\frac{1}{2}}$ |
| 6840.28 | 5 | 14615.25 | $5d\ ^4D_{3\frac{1}{2}} - 6f\ ^4F^\circ_{4\frac{1}{2}}$ |
| 6844.73 | 5 | 14605.75 | $5d\ ^4D_{3\frac{1}{2}} - 6f\ ^4D^\circ_{3\frac{1}{2}}$ |
| 6847.55 | 3 | 14599.73 | $5d\ ^4D_{3\frac{1}{2}} - 6f\ ^4P^\circ_{2\frac{1}{2}}$ |
| 6849.03 | 2 | 14596.58 | $5d\ ^4D_{3\frac{1}{2}} - 6f\ ^4F^\circ_{3\frac{1}{2}}$ |
| 6851.80 | 3 | 14590.68 | $5d\ ^4P_{2\frac{1}{2}} - 6f\ ^4P^\circ_{2\frac{1}{2}}$ |
| 6852.42 | 3 | 14589.36 | $5d\ ^4P_{2\frac{1}{2}} - 6f\ ^4S^\circ_{1\frac{1}{2}}$ |
| 6854.81 | 1 | 14584.27 | |
| 6857.68 | 2 | 14578.17 | |
| 6858.26 | 1 | 14576.94 | |
| 6863.57 | 1 | 14565.66 | |
| 6867.68 | 3 | 14556.94 | $5p\ ^2D^\circ_{1\frac{1}{2}} - 5d\ ^4D_{1\frac{1}{2}}$ |
| 6868.73 | 2 | 14554.72 | |
| 6878.77 | 40 | 14533.47 | $4p\ ^4D^\circ_{0\frac{1}{2}} - s^2\ ^4P_{0\frac{1}{2}}$ |
| 6884.23 | 50 | 14521.95 | $4p\ ^4D^\circ_{1\frac{1}{2}} - s^2\ ^4P_{1\frac{1}{2}}$ |
| 6889.74 | 100 | 14510.33 | |
| 6890.87 | 2 | 14507.95 | $5d\ ^4H_{6\frac{1}{2}} - 6f\ ^4H^\circ_{5\frac{1}{2}}$ |
| | | | $5d\ ^4P_{0\frac{1}{2}} - 6f\ ^4D^\circ_{1\frac{1}{2}}$ |
| | | | $5d\ ^2P_{1\frac{1}{2}} - 6f\ ^2P^\circ_{1\frac{1}{2}}$ |
| 6891.53 | 2 | 14506.56 | |
| 6897.73 | 5 | 14493.52 | $5d\ ^4H_{6\frac{1}{2}} - 6f\ ^4H^\circ_{6\frac{1}{2}}$ |
| 6899.02 | 2 | 14490.81 | |
| 6905.32 | 100 | 14477.59 | $5d\ ^4H_{6\frac{1}{2}} - 6f\ ^4I^\circ_{7\frac{1}{2}}$ |
| 6905.55 | 50 | 14477.11 | $5d\ ^4H_{3\frac{1}{2}} - 6f\ ^4I^\circ_{4\frac{1}{2}}$ |
| 6910.46 | 2 | 14466.83 | $4d'''\ ^2F_{2\frac{1}{2}} - 6f\ ^2G^\circ_{3\frac{1}{2}}$ |
| 6911.54 | 1 | 14464.57 | $5d\ ^2H_{5\frac{1}{2}} - 6f\ ^2H^\circ_{5\frac{1}{2}}$ |
| 6911.97 | 2 | 14463.67 | $5d\ ^4F_{1\frac{1}{2}} - 6f\ ^4G^\circ_{2\frac{1}{2}}$ |
| 6918.46 | 1 | 14450.10 | $5d\ ^4H_{4\frac{1}{2}} - 6f\ ^4H^\circ_{4\frac{1}{2}}$ |
| 6920.25 | 1 | 14446.36 | $5d\ ^4F_{1\frac{1}{2}} - 6f\ ^4F^\circ_{1\frac{1}{2}}$ |
| 6922.50 | 20 | 14441.66 | $5d\ ^4H_{5\frac{1}{2}} - 6f\ ^4G^\circ_{5\frac{1}{2}}$ |
| 6926.12 | 15 | 14434.12 | $5d\ ^4H_{5\frac{1}{2}} - 6f\ ^4H^\circ_{6\frac{1}{2}}$ |
| 6930.09 | 100 | 14425.85 | $5d\ ^2H_{5\frac{1}{2}} - 6f\ ^2I^\circ_{6\frac{1}{2}}$ |
| 6934.90 | 50 | 14415.84 | $5d\ ^4H_{4\frac{1}{2}} - 6f\ ^4I^\circ_{5\frac{1}{2}}$ |
| 6939.94 | 50 | 14405.37 | $5d\ ^4H_{5\frac{1}{2}} - 6f\ ^4I^\circ_{6\frac{1}{2}}$ |
| 6942.71 | 3 | 14399.63 | $5d\ ^2F_{3\frac{1}{2}} - 6f\ ^4H^\circ_{4\frac{1}{2}}$ |
| | | | $5d\ ^2H_{5\frac{1}{2}} - 6f'''\ ^2G^\circ_{4\frac{1}{2}}$ |
| 6943.87 | 5 | 14397.22 | $5d\ ^4G_{2\frac{1}{2}} - 6f\ ^4H^\circ_{3\frac{1}{2}}$ |
| 6945.02 | 1 | 14394.84 | $5d\ ^4F_{2\frac{1}{2}} - 6f\ ^4G^\circ_{3\frac{1}{2}}$ |
| 6946.34 | 5 | 14392.10 | $5d\ ^4G_{5\frac{1}{2}} - 6f\ ^4H^\circ_{5\frac{1}{2}}$ |
| | | | $5d\ ^4F_{2\frac{1}{2}} - 6f\ ^4D^\circ_{1\frac{1}{2}}$ |
| 6947.22 | 2 | 14390.28 | |
| 6947.41 | 1 | 14389.88 | $5d\ ^4H_{4\frac{1}{2}} - 4f'''\ ^2G^\circ_{4\frac{1}{2}}$ |
| 6948.08 | 5 | 14388.50 | $5d\ ^2F_{3\frac{1}{2}} - 6f\ ^2F^\circ_{3\frac{1}{2}}$ |
| 6948.53 | 3 | 14387.56 | $5d\ ^2F_{3\frac{1}{2}} - 6f\ ^2G^\circ_{4\frac{1}{2}}$ |
| 6953.30 | 40 | 14377.69 | $5d\ ^4G_{5\frac{1}{2}} - 6f\ ^4H^\circ_{6\frac{1}{2}}$ |
| 6958.25 | 50 | 14367.47 | $5d\ ^2H_{4\frac{1}{2}} - 6f\ ^2I^\circ_{5\frac{1}{2}}$ |
| 6961.28 | 30 | 14361.21 | $5d\ ^4F_{4\frac{1}{2}} - 6f\ ^4G^\circ_{5\frac{1}{2}}$ |
| 6962.72 | 20 | 14358.24 | $5d\ ^4F_{4\frac{1}{2}} - 6f\ ^4F^\circ_{4\frac{1}{2}}$ |
| 6966.49 | 30 | 14350.47 | $5d\ ^2G_{4\frac{1}{2}} - 6f\ ^2H^\circ_{5\frac{1}{2}}$ |
| 6967.24 | 50 | 14348.93 | $5d\ ^4G_{5\frac{1}{2}} - 6f\ ^4I^\circ_{6\frac{1}{2}}$ |
| 6971.59 | 2 | 14339.97 | $5d\ ^4P_{1\frac{1}{2}} - 6f\ ^4P^\circ_{1\frac{1}{2}}$ |
| 6974.59 | 5 | 14333.81 | $5d\ ^2G_{4\frac{1}{2}} - 6f\ ^2G^\circ_{4\frac{1}{2}}$ |
| 6978.32 | 2 | 14326.15 | |
| 6980.02 | 10 | 14322.66 | $5d\ ^4G_{3\frac{1}{2}} - 6f\ ^4H^\circ_{4\frac{1}{2}}$ |
| 6985.92 | 3 | 14310.56 | $5d\ ^4G_{3\frac{1}{2}} - 6f\ ^2G^\circ_{4\frac{1}{2}}$ |
| 6990.98 | 2 | 14300.20 | $5d\ ^4G_{3\frac{1}{2}} - 6f\ ^4F^\circ_{2\frac{1}{2}}$ |
| 6998.11 | 2 | 14285.63 | $5d\ ^2G_{4\frac{1}{2}} - 4f'''\ ^2G^\circ_{4\frac{1}{2}}$ |
| 6999.16 | 25 | 14283.49 | $5d\ ^4F_{3\frac{1}{2}} - 6f\ ^4G^\circ_{4\frac{1}{2}}$ |
| 6999.41 | 2 | 14282.98 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 5d\ ^4D_{2\frac{1}{2}}$ |
| 7002.34 | 1 | 14277.00 | $5d\ ^2G_{3\frac{1}{2}} - 6f\ ^2G^\circ_{3\frac{1}{2}}$ |
| 7002.64 | 15 | 14276.39 | $5d\ ^2G_{3\frac{1}{2}} - 6f\ ^2H^\circ_{4\frac{1}{2}}$ |
| 7006.33 | 2 | 14268.87 | $5d\ ^4F_{3\frac{1}{2}} - 6f\ ^4F^\circ_{4\frac{1}{2}}$ |
| 7011.10 | 2 | 14259.16 | $5d\ ^4F_{3\frac{1}{2}} - 6f\ ^4D^\circ_{3\frac{1}{2}}$ |
| 7015.63 | 5 | 14249.96 | $5d\ ^4F_{3\frac{1}{2}} - 6f\ ^4F^\circ_{3\frac{1}{2}}$ |
| 7017.83 | 1 | 14245.49 | $4p\ ^4D^\circ_{1\frac{1}{2}} - s^2\ ^4P_{2\frac{1}{2}}$ |
| 7019.85 | 10 | 14241.39 | $5d\ ^4G_{4\frac{1}{2}} - 6f\ ^4G^\circ_{4\frac{1}{2}}$ |
| 7022.17 | 50 | 14236.69 | $5d\ ^4G_{4\frac{1}{2}} - 6f\ ^4H^\circ_{5\frac{1}{2}}$ |
| 7022.65 | 2 | 14235.71 | $5p\ ^2F^\circ_{2\frac{1}{2}} - 5d\ ^4G_{3\frac{1}{2}}$ |
| 7025.97 | 2 | 14228.99 | |
| 7027.14 | 1 | 14226.62 | $5d\ ^4G_{4\frac{1}{2}} - 6f\ ^4F^\circ_{4\frac{1}{2}}$ |
| 7036.88 | 10 | 14206.93 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 5d\ ^4G_{4\frac{1}{2}}$ |
| 7085.86 | 3 | 14108.72 | $5d\ ^4D_{2\frac{1}{2}} - 6f\ ^4F^\circ_{3\frac{1}{2}}$ |
| 7097.45 | 3 | 14085.68 | $5p\ ^2D^\circ_{1\frac{1}{2}} - 5d\ ^4F_{2\frac{1}{2}}$ |
| 7101.52 | 30 | 14077.61 | |
| 7102.73 | 5h | 14075.21 | $5p\ ^2F^\circ_{3\frac{1}{2}} - 5d\ ^4F_{4\frac{1}{2}}$ |
| 7103.57 | 15 | 14073.55 | |
| 7104.44 | 5h | 14071.83 | |
| 7116.23 | 10 | 14048.51 | $5p\ ^2D^\circ_{2\frac{1}{2}} - 5d\ ^4P_{1\frac{1}{2}}$ |
| 7121.76 | 20 | 14037.60 | $4p\ ^2D^\circ_{2\frac{1}{2}} - s^2\ ^2G_{3\frac{1}{2}}$ |
| 7124.04 | 3h | 14033.11 | $5s'\ ^2D_{1\frac{1}{2}} - 5p'\ ^4P^\circ_{1\frac{1}{2}}$? |
| 7147.29 | 50 | 13987.46 | $4p\ ^2G^\circ_{3\frac{1}{2}} - s^2\ ^2G_{4\frac{1}{2}}$ |
| 7150.97 | 2 | 13980.26 | $4p\ ^4D^\circ_{0\frac{1}{2}} - s^2\ ^4P_{1\frac{1}{2}}$ |
| 7154.44 | 1 | 13973.48 | $5p\ ^2D^\circ_{1\frac{1}{2}} - 5d\ ^2P_{1\frac{1}{2}}$ |
| 7156.33 | 1 | 13969.79 | $5p\ ^2D^\circ_{1\frac{1}{2}} - 5d\ ^4P_{0\frac{1}{2}}$ |
| 7158.54 | 2 | 13965.48 | |
| 7187.98 | 5 | 13908.28 | |
| 7198.05 | 3 | 13888.82 | |
| 7235.44 | 20 | 13817.05 | $5p''\ ^4P^\circ_{2\frac{1}{2}} - 6s''\ ^4P_{1\frac{1}{2}}$ |
| 7249.15 | 5 | 13790.92 | $5p\ ^4D^\circ_{3\frac{1}{2}} - 6s\ ^2F_{3\frac{1}{2}}$ |
| 7261.11 | 10 | 13768.21 | |
| 7265.53 | 10 | 13759.83 | |
| 7295.00 | 3 | 13704.24 | $5p''\ ^4D^\circ_{3\frac{1}{2}} - 7d\ ^4F_{4\frac{1}{2}}$ |
| 7301.61 | 10 | 13691.84 | |
| 7301.93 | 20 | 13691.24 | $5p''\ ^4P^\circ_{1\frac{1}{2}} - 6s''\ ^4P_{0\frac{1}{2}}$ |
| 7325.63 | 300 | 13646.94 | $5p\ ^4F^\circ_{2\frac{1}{2}} - 6s\ ^2F_{2\frac{1}{2}}$ |
| | | | $5p''\ ^4P^\circ_{2\frac{1}{2}} - 6s''\ ^4P_{2\frac{1}{2}}$ |
| 7331.37 | 3 | 13636.26 | $5p''\ ^4D^\circ_{3\frac{1}{2}} - 7d\ ^4P_{2\frac{1}{2}}$ |
| 7337.92 | 3 | 13624.09 | $5p''\ ^4D^\circ_{3\frac{1}{2}} - 7d\ ^4D_{3\frac{1}{2}}$ |
| 7386.18 | 10 | 13535.07 | $5d\ ^4F_{1\frac{1}{2}} - 6f\ ^4D^\circ_{1\frac{1}{2}}$ |
| 7401.86 | 15 | 13506.40 | |
| 7404.37 | 2 | 13501.82 | |
| 7411.54 | 2 | 13488.76 | $5d\ ^2H_{4\frac{1}{2}} - 6f\ ^2F^\circ_{3\frac{1}{2}}$ |
| 7434.29 | 2 | 13447.48 | $5p''\ ^4P^\circ_{1\frac{1}{2}} - 6s''\ ^4P_{1\frac{1}{2}}$ |
| 7442.73 | 3 | 13432.23 | $5s''\ ^4P_{2\frac{1}{2}} - 5p''\ ^2D^\circ_{1\frac{1}{2}}$ |
| 7492.54 | 1 | 13342.93 | $5s\ ^4F_{3\frac{1}{2}} - 5p\ ^4F^\circ_{2\frac{1}{2}}$ |
| 7517.83 | 50 | 13298.05 | $5p''\ ^4P^\circ_{0\frac{1}{2}} - 6s''\ ^4P_{1\frac{1}{2}}$ |
| 7528.98 | 200 | 13278.36 | $4p\ ^2F^\circ_{3\frac{1}{2}} - s^2\ ^2G_{4\frac{1}{2}}$ |
| 7529.51 | 50 | 13277.42 | $5p''\ ^4P^\circ_{1\frac{1}{2}} - 6s''\ ^4P_{2\frac{1}{2}}$ |
| 7537.66 | 20 | 13263.06 | $5s\ ^4F_{3\frac{1}{2}} - 5p\ ^2G^\circ_{4\frac{1}{2}}$ |
| 7548.14 | 3 | 13244.65 | $4f\ ^2P^\circ_{1\frac{1}{2}} - 6s''\ ^4P_{2\frac{1}{2}}$ |
| 7556.27 | 10 | 13230.40 | $5s\ ^4F_{2\frac{1}{2}} - 5p\ ^2G^\circ_{3\frac{1}{2}}$ |
| 7585.11 | 150 | 13180.10 | $5p\ ^4D^\circ_{3\frac{1}{2}} - 6s\ ^4F_{4\frac{1}{2}}$ |
| 7595.83 | 1 | 13161.49 | |
| 7597.12 | 3 | 13159.26 | $5p'\ ^2D^\circ_{2\frac{1}{2}} - 6d\ ^2D_{2\frac{1}{2}}$ |
| 7603.49 | 5 | 13148.24 | $5p'''\ ^2H^\circ_{5\frac{1}{2}} - 6s'''\ ^2G_{4\frac{1}{2}}$ |
| 7638.38 | 5 | 13088.18 | $5s''\ ^4P_{2\frac{1}{2}} - 5p''\ ^4S^\circ_{1\frac{1}{2}}$ |
| 7644.74 | 10 | 13077.29 | |
| 7659.13 | 50 | 13052.72 | |
| 7678.07 | 2 | 13020.52 | |
| 7693.96 | 20 | 12993.63 | $5p\ ^4F^\circ_{4\frac{1}{2}} - 6s\ ^4F_{3\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 7706.08 | 2 | 12973.20 | |
| 7707.70 | 2 | 12970.47 | |
| 7711.24 | 200 | 12964.51 | $4p\,^2F^\circ_{2\frac{1}{2}} - s^2\,^2G_{3\frac{1}{2}}$ |
| 7726.35 | 3 | 12939.16 | |
| 7745.16 | 15 | 12907.74 | $5s''\,^4P_{1\frac{1}{2}} - 5p''\,^4S^\circ_{1\frac{1}{2}}$ |
| 7755.08 | 1 | 12891.23 | $4f\,^4F^\circ_{1\frac{1}{2}} - 5d'\,^2D_{2\frac{1}{2}}$ |
| 7755.34 | 1 | 12890.79 | |
| 7764.87 | 30 | 12874.97 | $5p\,^4D^\circ_{1\frac{1}{2}} - 6s\,^4F_{2\frac{1}{2}}$ |
| 7771.71 | 5 | 12863.64 | |
| 7785.95 | 15 | 12840.11 | |
| 7787.74 | 3 | 12837.16 | $5s''\,^4P_{1\frac{1}{2}} - 5p''\,^4D^\circ_{1\frac{1}{2}}$ |
| 7798.40 | 3 | 12819.62 | $5p''\,^2P^\circ_{1\frac{1}{2}} - 6s''\,^2P_{1\frac{1}{2}}$ |
| 7800.05 | 30 | 12816.90 | $5p\,^4G^\circ_{2\frac{1}{2}} - 6s\,^4F_{1\frac{1}{2}}$ |
| 7800.74 | 40 | 12815.77 | $5p\,^4G^\circ_{3\frac{1}{2}} - 6s\,^4F_{2\frac{1}{2}}$ |
| 7803.07 | 1 | 12811.94 | $5p''\,^4D^\circ_{3\frac{1}{2}} - 8s\,^4F_{4\frac{1}{2}}$ |
| 7803.32 | 0 | 12811.53 | $5p''\,^4D^\circ_{3\frac{1}{2}} - 6s''\,^2P_{1\frac{1}{2}}$ |
| 7804.27 | 30 | 12809.97 | $5s'''\,^2G_{3\frac{1}{2}} - 5p'''\,^2G^\circ_{3\frac{1}{2}}$ |
| 7807.61 | 75 | 12804.49 | $5s'''\,^2G_{4\frac{1}{2}} - 5p'''\,^2G^\circ_{4\frac{1}{2}}$ |
| 7811.73 | 10 | 12797.74 | $5s''\,^4P_{0\frac{1}{2}} - 5p''\,^4D^\circ_{0\frac{1}{2}}$ |
| 7812.34 | 2 | 12796.74 | $4f\,^4D^\circ_{3\frac{1}{2}} - 6d\,^4G_{2\frac{1}{2}}$ |
| 7816.19 | 5 | 12790.44 | |
| 7818.78 | 10 | 12786.20 | $5p'''\,^2F^\circ_{3\frac{1}{2}} - 6s'''\,^2G_{4\frac{1}{2}}$ |
| 7824.74 | 30 | 12776.46 | $5p\,^4G^\circ_{4\frac{1}{2}} - 6s\,^4F_{3\frac{1}{2}}$ |
| | | | $5s''\,^4P_{1\frac{1}{2}} - 5p''\,^2D^\circ_{2\frac{1}{2}}$ |
| 7825.68 | 2 | 12774.93 | |
| 7839.67 | 30 | 12752.13 | $5p\,^4F^\circ_{4\frac{1}{2}} - 6s\,^4F_{4\frac{1}{2}}$ |
| 7842.34 | 50 | 12747.79 | |
| 7845.10 | 1 | 12743.30 | $4f\,^4F^\circ_{1\frac{1}{2}} - 6d\,^4F_{1\frac{1}{2}}$? |
| 7848.34 | 3 | 12738.04 | |
| 7851.28 | 2 | 12733.27 | |
| 7852.82 | 20 | 12730.78 | $5p\,^4F^\circ_{1\frac{1}{2}} - 6s\,^4F_{1\frac{1}{2}}$ |
| 7868.58 | 40 | 12705.28 | $5p\,^2G^\circ_{4\frac{1}{2}} - 6s\,^2F_{3\frac{1}{2}}$ |
| 7875.01 | 30 | 12694.90 | $5p\,^2G^\circ_{3\frac{1}{2}} - 6s\,^2F_{2\frac{1}{2}}$ |
| 7876.19 | 1 | 12693.00 | $5s''\,^4P_{0\frac{1}{2}} - 5p''\,^4S^\circ_{1\frac{1}{2}}$ |
| 7880.64 | 100 | 12685.83 | $5p\,^4G^\circ_{5\frac{1}{2}} - 6s\,^4F_{4\frac{1}{2}}$ |
| 7882.70 | 0 | 12682.52 | $5s''\,^4P_{2\frac{1}{2}} - 5p''\,^4D^\circ_{2\frac{1}{2}}$ |
| 7884.84 | 2 | 12679.08 | |
| 7905.44 | 30 | 12646.04 | $5p\,^4F^\circ_{2\frac{1}{2}} - 6s\,^4F_{2\frac{1}{2}}$ |
| 7914.39 | 1 | 12631.74 | |
| 7920.21 | 25 | 12622.46 | $5s''\,^4P_{0\frac{1}{2}} - 5p''\,^4D^\circ_{1\frac{1}{2}}$ |
| 7921.19 | 10 | 12620.89 | |
| 7925.05 | 20 | 12614.75 | |
| 7935.53 | 5h | 12598.09 | |
| 7944.58 | 2h | 12583.74 | |
| 7951.99 | 2 | 12572.01 | |
| 7952.32 | 40 | 12571.49 | $5p\,^4D^\circ_{2\frac{1}{2}} - 6s\,^4F_{3\frac{1}{2}}$ |
| | | | $5p''\,^2P^\circ_{1\frac{1}{2}} - 6s''\,^4P_{1\frac{1}{2}}$ |
| 7957.52 | 300 | 12563.27 | $5p''\,^4D^\circ_{2\frac{1}{2}} - 6s''\,^4P_{1\frac{1}{2}}$ |
| 7962.41 | 150 | 12555.56 | $5s'\,^2D_{2\frac{1}{2}} - 5p'\,^2F^\circ_{3\frac{1}{2}}$ |
| 7963.36 | 20 | 12554.06 | |
| 7965.02 | 8 | 12551.44 | |
| 7965.54 | 3 | 12550.62 | $5d\,^4D_{1\frac{1}{2}} - 6f\,^4F^\circ_{1\frac{1}{2}}$ |
| 7971.90 | 200 | 12540.61 | $5p''\,^4D^\circ_{3\frac{1}{2}} - 6s''\,^4P_{2\frac{1}{2}}$ |
| 7973.87 | 2 | 12537.51 | |
| 7974.14 | 30 | 12537.09 | $6s''\,^2P_{1\frac{1}{2}} - 5p''\,^2D^\circ_{2\frac{1}{2}}$ |
| 7975.39 | 100 | 12535.12 | $5s''\,^4P_{2\frac{1}{2}} - 5p''\,^4D^\circ_{3\frac{1}{2}}$ |
| 7981.78 | 10 | 12525.09 | |
| 7982.98 | 3 | 12523.21 | $4f\,^4D^\circ_{0\frac{1}{2}} - 6s''\,^4P_{1\frac{1}{2}}$ |
| 7986.81 | 1 | 12517.20 | $5p''\,^4D^\circ_{1\frac{1}{2}} - 5d'\,^2D_{1\frac{1}{2}}$ |
| 7988.17 | 3h | 12515.07 | |
| 7988.64 | 15 | 12514.33 | |
| 7992.64 | 10 | 12508.07 | |
| 7996.48 | 50 | 12502.06 | $5s''\,^4P_{1\frac{1}{2}} - 5p''\,^4D^\circ_{2\frac{1}{2}}$ |
| 7998.03 | 2 | 12499.64 | $5p'\,^2P^\circ_{1\frac{1}{2}} - 6s'\,^2D_{1\frac{1}{2}}$ |
| 7998.56 | 2 | 12498.81 | $5s'\,^2D_{1\frac{1}{2}} - 5p'\,^2P^\circ_{0\frac{1}{2}}$ |
| 7998.97 | 100 | 12498.17 | $5s\,^4F_{4\frac{1}{2}} - 5p\,^4G^\circ_{4\frac{1}{2}}$ |
| 8001.64 | 5 | 12494.00 | $5s''\,^4P_{1\frac{1}{2}} - 5p''\,^2P^\circ_{1\frac{1}{2}}$ |
| 8003.73 | 5 | 12490.74 | |
| 8006.25 | 2 | 12486.81 | |
| 8007.15 | 2 | 12485.40 | |
| 8008.85 | 8 | 12482.75 | |
| 8009.81 | 20 | 12481.26 | |
| 8012.61 | 8 | 12476.90 | $5p\,^2F^\circ_{3\frac{1}{2}} - 6s\,^4F_{2\frac{1}{2}}$? |
| 8012.91 | 2 | 12476.43 | $5p''\,^4D^\circ_{1\frac{1}{2}} - 6s''\,^2P_{1\frac{1}{2}}$ |
| 8014.02 | 1 | 12474.70 | |
| 8014.77 | 40 | 12473.53 | |
| 8015.79 | 75 | 12471.95 | $5p''\,^4D^\circ_{1\frac{1}{2}} - 6s''\,^4P_{0\frac{1}{2}}$ |
| 8017.40 | 40 | 12469.44 | |
| 8019.00 | 2 | 12466.95 | $4f\,^4G^\circ_{2\frac{1}{2}} - 6s''\,^4P_{1\frac{1}{2}}$ |
| 8020.56 | 5 | 12464.53 | |
| 8020.95 | 2 | 12463.92 | |
| 8021.81 | 50 | 12462.59 | |
| 8022.68 | 2 | 12461.24 | |
| 8024.87 | 20 | 12457.83 | $5p'\,^2P^\circ_{1\frac{1}{2}} - 6s'\,^2D_{2\frac{1}{2}}$ |
| 8025.97 | 50 | 12456.13 | $5p\,^2F^\circ_{3\frac{1}{2}} - 6s\,^2F_{3\frac{1}{2}}$ |
| 8028.49 | 15 | 12452.22 | $4f\,^4F^\circ_{1\frac{1}{2}} - 6s''\,^4P_{1\frac{1}{2}}$ |
| 8031.22 | 0 | 12447.98 | $5s\,^4F_{2\frac{1}{2}} - 5p\,^2F^\circ_{3\frac{1}{2}}$ |
| 8032.07 | 1 | 12446.67 | $5p''\,^4S^\circ_{1\frac{1}{2}} - 5d'\,^2D_{1\frac{1}{2}}$ |
| 8035.38 | 20 | 12441.54 | $5p''\,^2D^\circ_{1\frac{1}{2}} - 6s''\,^2P_{0\frac{1}{2}}$ |
| 8036.82 | 1 | 12439.31 | |
| 8036.95 | 5 | 12439.11 | |
| 8039.68 | 15 | 12434.89 | $5s'\,^2D_{2\frac{1}{2}} - 5p'\,^2P^\circ_{1\frac{1}{2}}$ |
| 8040.92 | 30 | 12432.97 | $5p\,^2D^\circ_{2\frac{1}{2}} - 6s\,^2F_{3\frac{1}{2}}$ |
| 8044.01 | 75 | 12428.19 | $5p\,^4F_{3\frac{1}{2}} - 6s\,^4F_{3\frac{1}{2}}$ |
| 8048.06 | 25 | 12421.94 | |
| 8053.54 | 5 | 12413.49 | |
| 8053.94 | 150 | 12412.87 | $5s\,^2F_{2\frac{1}{2}} - 5p\,^2D^\circ_{1\frac{1}{2}}$ |
| 8058.49 | 15 | 12405.86 | $5p''\,^4S^\circ_{1\frac{1}{2}} - 6s''\,^2P_{1\frac{1}{2}}$ |
| 8061.41 | 5 | 12401.37 | $5p''\,^4S^\circ_{1\frac{1}{2}} - 6s''\,^4P_{0\frac{1}{2}}$ |
| | | | $5p''\,^2P^\circ_{1\frac{1}{2}} - 6s''\,^4P_{2\frac{1}{2}}$ |
| 8064.29 | 10 | 12396.94 | |
| 8066.32 | 3 | 12393.82 | $5p''\,^4D^\circ_{0\frac{1}{2}} - 5d'\,^2P_{0\frac{1}{2}}$ |
| 8066.68 | 2 | 12393.27 | $5p''\,^4D^\circ_{2\frac{1}{2}} - 6s''\,^4P_{2\frac{1}{2}}$ |
| 8070.58 | 2 | 12387.28 | |
| 8071.30 | 1 | 12386.17 | |
| 8078.09 | 1 | 12375.76 | $4p''\,^4P^\circ_{1\frac{1}{2}} - s^2\,^2D_{1\frac{1}{2}}$ |
| 8078.78 | 1 | 12374.70 | |
| 8084.12 | 1 | 12366.53 | |
| 8087.02 | 50 | 12362.09 | |
| 8093.00 | 300 | 12352.96 | $5s\,^2F_{2\frac{1}{2}} - 5p\,^2F^\circ_{2\frac{1}{2}}$ |
| 8094.23 | 5 | 12351.08 | |
| 8096.75 | 1000 | 12347.24 | $5s\,^4F_{4\frac{1}{2}} - 5p\,^4G^\circ_{5\frac{1}{2}}$ |
| 8100.66 | 5 | 12341.28 | |
| 8106.26 | 300 | 12332.75 | $5s\,^2F_{3\frac{1}{2}} - 5p\,^2D^\circ_{2\frac{1}{2}}$ |
| 8108.52 | 1 | 12329.32 | |
| 8109.39 | 15 | 12327.99 | |
| 8114.21 | 500 | 12320.67 | $5s\,^4F_{3\frac{1}{2}} - 5p\,^4F^\circ_{3\frac{1}{2}}$ |
| 8117.80 | 2 | 12315.22 | |
| 8121.00 | 10 | 12310.37 | $5p'\,^2P^\circ_{0\frac{1}{2}} - 6s'\,^2D_{1\frac{1}{2}}$ |
| 8121.48 | 700 | 12309.64 | $5s\,^2F_{3\frac{1}{2}} - 5p\,^2F^\circ_{3\frac{1}{2}}$ |

TABLE I. *Lines of* Ni II — Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 8126.42 | 75 | 12302.16 | $5s\,^4F_{11/2}-5p\,^4F^\circ_{11/2}$ |
| 8130.06 | 25 | 12296.65 | $5p''\,^4D^\circ_{03/2}-6s''\,^4P_{01/2}$ |
| 8135.04 | 3 | 12289.12 | |
| 8135.98 | 5 | 12287.70 | |
| 8140.45 | 100 | 12280.96 | $5s\,^4F_{41/2}-5p\,^4F^\circ_{41/2}$ |
| 8141.94 | 50 | 12278.71 | $5s\,^4F_{31/2}-5p\,^4F^\circ_{21/2}$ |
| 8143.09 | 5 | 12276.97 | |
| 8148.80 | 1 | 12268.37 | |
| 8153.49 | 5 | 12261.32 | |
| 8158.26 | 10 | 12254.15 | |
| 8163.49 | 30 | 12246.30 | $5s'''\,^2G_{31/2}-5p'''\,^2F^\circ_{31/2}$ |
| 8164.87 | 3 | 12244.23 | |
| 8166.92 | 2 | 12241.15 | |
| 8172.20 | 25 | 12233.24 | $5p\,^2F^\circ_{21/2}-6s\,^2F_{21/2}$ |
| 8175.54 | 3 | 12228.25 | $5p''\,^4D^\circ_{11/2}-6s''\,^4P_{11/2}$ |
| 8177.51 | 1 | 12225.30 | |
| 8183.72 | 100 | 12216.02 | $5s\,^4F_{11/2}-5p\,^4G^\circ_{21/2}$ |
| 8184.38 | 3 | 12215.04 | |
| 8192.04 | 2 | 12203.62 | |
| 8194.83 | 1 | 12199.46 | |
| 8203.59 | 5 | 12186.43 | $5s''\,^2P_{11/2}-5p''\,^4S^\circ_{11/2}$ |
| 8208.21 | 1 | 12179.58 | |
| 8209.70 | 150 | 12177.37 | $5s\,^4F_{31/2}-5p\,^4D^\circ_{21/2}$ |
| 8211.97 | 3 | 12174.00 | $5p\,^4D^\circ_{31/2}-4d''\,^4F_{31/2}$ |
| 8212.39 | 10 | 12173.38 | $5p\,^2D^\circ_{11/2}-6s\,^2F_{21/2}$ |
| 8222.99 | 8 | 12157.68 | $5p''\,^4S^\circ_{11/2}-6s''\,^4P_{11/2}$ |
| 8224.04 | 5 | 12156.13 | |
| 8235.91 | 50 | 12138.61 | $5s'''\,^2G_{41/2}-5p'''\,^2F^\circ_{31/2}$ |
| 8236.96 | 1 | 12137.07 | |
| 8242.99 | 3h | 12128.19 | |
| 8245.41 | 10 | 12124.63 | $5s''\,^2P_{01/2}-5p''\,^2D^\circ_{11/2}$ |
| 8245.91 | 2 | 12123.89 | |
| 8248.36 | 5 | 12120.29 | $5p'''\,^2G^\circ_{41/2}-6s'''\,^2G_{41/2}$ |
| 8249.37 | 30 | 12118.81 | $6s''\,^4P_{21/2}-5p''\,^2D^\circ_{21/2}$ |
| 8256.06 | 200 | 12108.99 | $5s\,^4F_{21/2}-5p\,^4G^\circ_{31/2}$ |
| 8256.52 | 5 | 12108.31 | |
| 8263.62 | 3 | 12097.91 | |
| 8266.38 | 2 | 12093.87 | |
| 8271.96 | 3 | 12085.71 | |
| 8275.38 | 3 | 12080.72 | |
| 8289.30 | 200 | 12060.43 | $5s\,^2F_{31/2}-5p\,^2G^\circ_{41/2}$ |
| 8290.89 | 5 | 12058.12 | $5p''\,^4D^\circ_{11/2}-6s''\,^4P_{21/2}$ |
| 8292.88 | 5 | 12055.22 | $5s''\,^2P_{11/2}-5p''\,^2D^\circ_{21/2}$ |
| 8296.62 | 100 | 12049.79 | $5s\,^4F_{21/2}-5p\,^4D^\circ_{11/2}$ |
| 8320.34 | 0 | 12015.44 | $4d''\,^2P_{11/2}-5f\,^4D^\circ_{21/2}$ |
| 8322.57 | 2 | 12012.22 | |
| 8339.68 | 15 | 11987.57 | $5p''\,^4S^\circ_{11/2}-6s''\,^4P_{21/2}$ |
| 8350.26 | 200 | 11972.38 | $5s\,^4F_{31/2}-5p\,^4G^\circ_{41/2}$ |
| 8350.94 | 2 | 11971.41 | |
| 8351.50 | 1 | 11970.61 | $5s\,^2F_{31/2}-5p\,^4G^\circ_{31/2}$ |
| 8354.06 | 2 | 11966.94 | |
| 8355.66 | 30 | 11964.65 | $5s'\,^2D_{21/2}-\ w\,^4F^\circ_{31/2}$ |
| 8361.74 | 15 | 11955.95 | |
| 8361.98 | 25 | 11955.60 | $5s\,^4F_{11/2}-5p\,^4D^\circ_{01/2}$ |
| 8379.50 | 20 | 11930.61 | |
| 8407.21 | 150 | 11891.28 | $5s\,^2F_{21/2}-5p\,^2G^\circ_{31/2}$ |
| 8415.11 | 1 | 11880.12 | |
| 8425.92 | 50 | 11864.88 | $5s'\,^2D_{21/2}-5p'\,^2D^\circ_{21/2}$ |
| 8434.38 | 150 | 11852.98 | $5s\,^4F_{41/2}-5p\,^4D^\circ_{31/2}$ |
| 8473.40 | 10 | 11798.40 | $5s''\,^4P_{21/2}-5p''\,^4P^\circ_{11/2}$ |
| 8486.09 | 15 | 11780.75 | $5s''\,^2P_{11/2}-5p''\,^4D^\circ_{21/2}$ |
| 8489.08 | 25 | 11776.60 | $5s'''\,^2G_{41/2}-5p'''\,^2H^\circ_{31/2}$ |
| 8491.90 | 3 | 11772.69 | $5s''\,^2P_{11/2}-5p''\,^2P^\circ_{11/2}$ |
| 8495.70 | 5 | 11767.43 | $5s''\,^4P_{11/2}-5p''\,^4P^\circ_{01/2}$ |
| 8503.93 | 0 | 11756.04 | $6s'\,^2D_{21/2}-5p'\,^2D^\circ_{11/2}$ |
| 8504.52 | 75 | 11755.22 | $5s\,^4F_{31/2}-5p\,^4F_{41/2}$ |
| 8508.84 | 3 | 11749.26 | |
| 8527.73 | 3 | 11723.23 | |
| 8537.35 | 1 | 11710.02 | $5s''\,^2P_{01/2}-5p''\,^4D^\circ_{11/2}$ |
| 8549.16 | 10 | 11693.84 | |
| 8563.38 | 1 | 11674.42 | |
| 8576.99 | 3 | 11655.90 | |
| 8577.97 | 1 | 11654.57 | |
| 8580.40 | 1 | 11651.27 | |
| 8586.11 | 10 | 11643.52 | $5p''\,^2D^\circ_{11/2}-6s''\,^4P_{21/2}$ |
| 8594.49 | 2 | 11632.17 | |
| 8595.54 | 3 | 11630.75 | $5s'\,^2D_{11/2}-5p'\,^2D^\circ_{11/2}$ |
| 8605.05 | 0 | 11617.89 | $5s''\,^4P_{11/2}-5p''\,^4P^\circ_{11/2}$ |
| 8608.01 | 20 | 11613.90 | $5d\,^2P_{11/2}-4f'\,^2F^\circ_{21/2}$ |
| 8622.32 | 30 | 11594.62 | $5s'''\,^2G_{31/2}-5p'''\,^2H^\circ_{41/2}$ |
| 8644.68 | 3h | 11564.63 | |
| 8652.66 | 0 | 11553.97 | $5s\,^2F_{21/2}-5p\,^4G^\circ_{21/2}$ |
| 8708.07 | 2 | 11480.45 | |
| 8715.99 | 1 | 11470.02 | |
| 8723.56 | 1 | 11460.06 | |
| 8729.03 | 2 | 11452.88 | $4f\,^4\,I^\circ_{71/2}-5g\,^4K_{61/2}$ |
| 8735.96 | 5 | 11443.80 | |
| 8738.68 | 1 | 11440.23 | |
| 8741.99 | 2 | 11435.90 | $5s''\,^4P_{01/2}-4f\,^2P^\circ_{11/2}$ |
| 8744.16 | 10 | 11433.06 | |
| 8747.39 | 30 | 11428.84 | $5s''\,^4P_{21/2}-5p''\,^4P^\circ_{21/2}$ |
| 8755.37 | 5 | 11418.43 | |
| 8767.07 | 3 | 11403.19 | $5s''\,^4P_{01/2}-5p''\,^4P^\circ_{11/2}$ |
| 8767.89 | 1 | 11402.12 | $4f\,^2F^\circ_{31/2}-6d\,^4G_{21/2}$ |
| 8770.16 | 1 | 11399.17 | $4f\,^4G^\circ_{41/2}-5g\,^4\,I_{51/2}$ |
| 8778.95 | 1 | 11387.76 | |
| 8790.59 | 1 | 11372.68 | $5s\,^4F_{11/2}-5p\,^4D^\circ_{11/2}$ |
| 8798.93 | 50 | 11361.90 | |
| 8806.33 | 1 | 11352.35 | |
| 8815.14 | 3 | 11341.01 | |
| 8827.31 | 1 | 11325.37 | |
| 8850.42 | 2 | 11295.80 | |
| 8867.83 | 10 | 11273.62 | |
| 8881.32 | 0 | 11256.50 | $5s\,^4F_{21/2}-5p\,^4F_{31/2}$ |
| 8887.74 | 3 | 11248.37 | $5s''\,^4P_{11/2}-5p''\,^4P_{21/2}$ |
| 8897.00 | 2 | 11236.66 | $5p\,^2F^\circ_{31/2}-6s\,^4F_{31/2}$ |
| 8900.22 | 0 | 11232.59 | $5p\,^2F^\circ_{21/2}-6s\,^4F_{21/2}$ |
| 8909.43 | 5 | 11220.98 | |
| 8915.37 | 5 | 11213.51 | $5p\,^2D^\circ_{21/2}-6s\,^4F_{31/2}$ |
| 8965.58 | 3 | 11150.71 | |
| 9006.58 | 3 | 11099.95 | |
| 9086.56 | 30 | 11002.24 | |
| 9109.31 | 5 | 10974.77 | $5s\,^2F_{31/2}-5p\,^4D^\circ_{21/2}$ |
| 9255.77 | 3 | 10801.11 | $4p'\,^2D^\circ_{11/2}-\ s^2\,^2D_{11/2}$ |
| 9282.76 | 10 | 10769.70 | $5s\,^2F_{31/2}-5p\,^4G^\circ_{41/2}$ |
| 9777.86 | 3 | 10224.38 | |
| 9820.01 | 1 | 10180.50 | $4f\,^2D^\circ_{11/2}-5g\,^2F_{21/2}$ |
| 9824.11 | 10 | 10176.25 | |
| 9830.49 | 1 | 10169.64 | |
| 9830.78 | 10 | 10169.34 | |

TABLE I. *Lines of* Ni II – Continued

| λ(air) | Intensity | Wavenumber | Transition |
|---|---|---|---|
| 9834.94 | 5 | 10165.04 | $4f\ ^2S^\circ_{0\frac{1}{2}} - 5g\ ^4P_{1\frac{1}{2}}$ |
| 9837.15 | 3 | 10162.76 | $4f\ ^4I^\circ_{6\frac{1}{2}} - 5g\ ^4G_{5\frac{1}{2}}$ |
| 9842.82 | 15 | 10156.90 | $4f\ ^4I^\circ_{6\frac{1}{2}} - 5g\ ^4H_{5\frac{1}{2}}$ |
| 9856.97 | 300 | 10142.32 | $4f\ ^4I^\circ_{6\frac{1}{2}} - 5g\ ^4K_{7\frac{1}{2}}$ |
| 9859.02 | 2 | 10140.22 | |
| 9861.94 | 10 | 10137.21 | |
| 9863.45 | 10 | 10135.66 | |
| 9865.69 | 2 | 10133.36 | |
| 9866.77 | 2 | 10132.25 | $4f\ ^4D^\circ_{0\frac{1}{2}} - 5g\ ^4F_{1\frac{1}{2}}$ |
| 9876.55 | 20 | 10122.22 | $4f\ ^4P^\circ_{2\frac{1}{2}} - 5g\ ^4D_{3\frac{1}{2}}$ |
| 9877.61 | 30 | 10121.13 | $4f\ ^4I^\circ_{6\frac{1}{2}} - 5g\ ^4I_{6\frac{1}{2}}$ |
| 9881.24 | 5 | 10117.41 | $4f\ ^4F^\circ_{2\frac{1}{2}} - 5g\ ^4G_{3\frac{1}{2}}$ |
| 9882.92 | 40 | 10115.69 | $4f\ ^4P^\circ_{2\frac{1}{2}} - 5g\ ^4D_{2\frac{1}{2}}$ |
| 9883.67 | 0 | 10114.93 | $4f\ ^2P^\circ_{1\frac{1}{2}} - 5g\ ^4F_{2\frac{1}{2}}$ |
| 9886.09 | 2 | 10112.45 | $4f\ ^2I^\circ_{5\frac{1}{2}} - 5g\ ^2H_{4\frac{1}{2}}$ |
| 9886.69 | 30 | 10111.84 | $4f\ ^4I^\circ_{7\frac{1}{2}} - 5g\ ^4H_{6\frac{1}{2}}$ |
| 9887.35 | 5 | 10111.16 | $4f\ ^4P^\circ_{2\frac{1}{2}} - 5g\ ^4P_{1\frac{1}{2}}$ |
| 9887.96 | 50 | 10110.54 | $4f\ ^2I^\circ_{5\frac{1}{2}} - 5g\ ^2K_{6\frac{1}{2}}$<br>$4f\ ^4F^\circ_{2\frac{1}{2}} - 5g\ ^4F_{2\frac{1}{2}}$ |
| 9890.57 | 20w | 10107.87 | $4f\ ^4I^\circ_{4\frac{1}{2}} - 5g\ ^4H_{3\frac{1}{2}}$ |
| 9894.83 | 30 | 10103.52 | $4f\ ^2I^\circ_{6\frac{1}{2}} - 5g\ ^2H_{5\frac{1}{2}}$ |
| 9896.09 | 3 | 10102.23 | $4f\ ^4I^\circ_{5\frac{1}{2}} - 5g\ ^4I_{5\frac{1}{2}}$ |
| 9900.56 | 100 | 10097.67 | $4f\ ^2I^\circ_{5\frac{1}{2}} - 5g\ ^2K_{6\frac{1}{2}}$ |
| 9900.92 | 500w | 10097.30 | $4f\ ^4I^\circ_{7\frac{1}{2}} - 5g\ ^4K_{8\frac{1}{2}}$<br>$4f\ ^2I^\circ_{5\frac{1}{2}} - 5g\ ^2I_{5\frac{1}{2}}$ |
| 9905.03 | 100 | 10093.11 | $4f\ ^2I^\circ_{6\frac{1}{2}} - 5g\ ^2K_{7\frac{1}{2}}$ |
| 9906.90 | 3 | 10091.21 | $4f\ ^4D^\circ_{1\frac{1}{2}} - 5g\ ^4F_{2\frac{1}{2}}$ |
| 9907.60 | 200 | 10090.49 | $4f\ ^4D^\circ_{3\frac{1}{2}} - 5g\ ^4F_{4\frac{1}{2}}$<br>$4f\ ^4I^\circ_{5\frac{1}{2}} - 5g\ ^4K_{6\frac{1}{2}}$ |
| 9913.77 | 40 | 10084.21 | $4f\ ^4P^\circ_{2\frac{1}{2}} - 5g\ ^4P_{2\frac{1}{2}}$ |
| 9921.12 | 20 | 10076.74 | $4f\ ^4D^\circ_{3\frac{1}{2}} - 5g\ ^4D_{3\frac{1}{2}}$ |
| 9921.85 | 30 | 10076.00 | $4f\ ^4G^\circ_{2\frac{1}{2}} - 5g\ ^4F_{1\frac{1}{2}}$?<br>$4f\ ^4I^\circ_{7\frac{1}{2}} - 5g\ ^4I_{6\frac{1}{2}}$ |
| 9923.28 | 0 | 10074.55 | $4f\ ^4G^\circ_{3\frac{1}{2}} - 5g\ ^2G_{4\frac{1}{2}}$ |
| 9923.98 | 1 | 10073.84 | |
| 9924.29 | 5 | 10073.53 | $4f\ ^4H^\circ_{5\frac{1}{2}} - 5g\ ^4G_{4\frac{1}{2}}$ |
| 9924.55 | 8 | 10073.26 | $4f\ ^4H^\circ_{6\frac{1}{2}} - 5g\ ^4G_{5\frac{1}{2}}$ |
| 9927.02 | 30 | 10070.76 | $4f\ ^4G^\circ_{3\frac{1}{2}} - 5g\ ^4G_{3\frac{1}{2}}$ |
| 9927.54 | 2 | 10070.23 | $4f\ ^4D^\circ_{3\frac{1}{2}} - 5g\ ^4D_{2\frac{1}{2}}$ |
| 9929.98 | 75 | 10067.75 | $4f\ ^4H^\circ_{5\frac{1}{2}} - 5g\ ^4H_{5\frac{1}{2}}$ |
| 9930.24 | 100 | 10067.49 | $4f\ ^4H^\circ_{6\frac{1}{2}} - 5g\ ^4H_{6\frac{1}{2}}$ |
| 9930.52 | 2 | 10067.21 | $4f\ ^4P^\circ_{1\frac{1}{2}} - 5g\ ^4D_{2\frac{1}{2}}$ |
| 9932.81 | 2 | 10064.88 | |
| 9933.81 | 5 | 10063.87 | $4f\ ^4G^\circ_{3\frac{1}{2}} - 5g\ ^4F_{2\frac{1}{2}}$ |
| 9935.03 | 0 | 10062.64 | $4f\ ^4P^\circ_{1\frac{1}{2}} - 5g\ ^4P_{1\frac{1}{2}}$ |
| 9936.48 | 5 | 10061.17 | $4f\ ^4F^\circ_{1\frac{1}{2}} - 5g\ ^4F_{1\frac{1}{2}}$ |
| 9937.19 | 10 | 10060.45 | $4f\ ^4D^\circ_{2\frac{1}{2}} - 5g\ ^4F_{3\frac{1}{2}}$ |
| 9941.70 | 20 | 10055.88 | $4f\ ^2F^\circ_{3\frac{1}{2}} - 5g\ ^2G_{4\frac{1}{2}}$ |
| 9942.81 | 3 | 10054.76 | $4f\ ^2G^\circ_{3\frac{1}{2}} - 5g\ ^2H_{4\frac{1}{2}}$ |
| 9943.29 | 40 | 10054.28 | $4f\ ^2H^\circ_{5\frac{1}{2}} - 5g\ ^2G_{4\frac{1}{2}}$ |
| 9944.60 | 3 | 10052.95 | $4f\ ^4D^\circ_{2\frac{1}{2}} - 5g\ ^4D_{3\frac{1}{2}}$ |
| 9944.76 | 50 | 10052.79 | $4f\ ^2H^\circ_{4\frac{1}{2}} - 5g\ ^2H_{4\frac{1}{2}}$ |
| 9945.37 | 40w | 10052.17 | $4f\ ^4G^\circ_{4\frac{1}{2}} - 5g\ ^4G_{4\frac{1}{2}}$<br>$4f\ ^2F^\circ_{3\frac{1}{2}} - 5g\ ^4G_{3\frac{1}{2}}$<br>$4f\ ^4H^\circ_{4\frac{1}{2}} - 5g\ ^2G_{4\frac{1}{2}}$ |
| 9946.24 | 75 | 10051.29 | $4f\ ^2H^\circ_{5\frac{1}{2}} - 5g\ ^2H_{5\frac{1}{2}}$ |
| 9947.25 | 15 | 10050.27 | $4f\ ^4G^\circ_{4\frac{1}{2}} - 5g\ ^4F_{4\frac{1}{2}}$ |
| 9948.29 | 30 | 10049.22 | $4f\ ^4H^\circ_{4\frac{1}{2}} - 5g\ ^2H_{5\frac{1}{2}}$ |
| 9948.51 | 10 | 10049.00 | $4f\ ^2D^\circ_{2\frac{1}{2}} - 5g\ ^4G_{3\frac{1}{2}}$ |
| 9951.10 | 1 | 10046.39 | $4f\ ^4D^\circ_{2\frac{1}{2}} - 5g\ ^4D_{2\frac{1}{2}}$ |
| 9952.24 | 0 | 10045.23 | $4f\ ^2F^\circ_{3\frac{1}{2}} - 5g\ ^4F_{2\frac{1}{2}}$ |
| 9953.04 | 2 | 10044.43 | $4f\ ^2G^\circ_{3\frac{1}{2}} - 5g\ ^2F_{2\frac{1}{2}}$ |
| 9953.48 | 5 | 10043.98 | $4f\ ^4G^\circ_{4\frac{1}{2}} - 5g\ ^4F_{3\frac{1}{2}}$ |
| 9953.83 | 30 | 10043.63 | $4f\ ^2G^\circ_{4\frac{1}{2}} - 5g\ ^2G_{4\frac{1}{2}}$ |
| 9955.34 | 3 | 10042.11 | $4f\ ^2D^\circ_{2\frac{1}{2}} - 5g\ ^4F_{2\frac{1}{2}}$ |
| 9956.00 | 15 | 10041.44 | $4f\ ^4F^\circ_{3\frac{1}{2}} - 5g\ ^4F_{4\frac{1}{2}}$ |
| 9956.44 | 15 | 10041.00 | $4f\ ^4H^\circ_{4\frac{1}{2}} - 5g\ ^4I_{5\frac{1}{2}}$<br>$4f\ ^4H^\circ_{3\frac{1}{2}} - 5g\ ^2H_{4\frac{1}{2}}$ |
| 9956.88 | 5 | 10040.55 | $4f\ ^2H^\circ_{4\frac{1}{2}} - 5g\ ^2G_{3\frac{1}{2}}$ |
| 9957.61 | 3 | 10039.82 | $4f\ ^2G^\circ_{4\frac{1}{2}} - 5g\ ^4G_{3\frac{1}{2}}$ |
| 9957.92 | 10 | 10039.51 | $4f\ ^4F^\circ_{4\frac{1}{2}} - 5g\ ^4G_{5\frac{1}{2}}$ |
| 9958.73 | 20 | 10038.69 | $4f\ ^4D^\circ_{3\frac{1}{2}} - 5g\ ^4P_{2\frac{1}{2}}$ |
| 9959.79 | 20 | 10037.62 | $4f\ ^4F^\circ_{4\frac{1}{2}} - 5g\ ^4F_{4\frac{1}{2}}$ |
| 9962.20 | 10 | 10035.19 | $4f\ ^4F^\circ_{3\frac{1}{2}} - 5g\ ^4F_{3\frac{1}{2}}$ |
| 9966.02 | 5 | 10031.35 | $4f\ ^4F^\circ_{4\frac{1}{2}} - 5g\ ^4F_{3\frac{1}{2}}$ |
| 9968.50 | 0 | 10028.85 | $4f\ ^2F^\circ_{2\frac{1}{2}} - 5g\ ^2F_{2\frac{1}{2}}$ |
| 9969.66 | 0 | 10027.68 | $4f\ ^4F^\circ_{3\frac{1}{2}} - 5g\ ^4D_{3\frac{1}{2}}$ |
| 9970.40 | 75 | 10026.94 | $4f\ ^4G^\circ_{5\frac{1}{2}} - 5g\ ^4G_{5\frac{1}{2}}$<br>$4f\ ^2F^\circ_{2\frac{1}{2}} - 5g\ ^2G_{3\frac{1}{2}}$ |
| 9972.30 | 15 | 10025.03 | $4f\ ^4G^\circ_{5\frac{1}{2}} - 5g\ ^4F_{4\frac{1}{2}}$ |
| 9973.47 | 0 | 10023.85 | $4f\ ^4F^\circ_{4\frac{1}{2}} - 5g\ ^4D_{3\frac{1}{2}}$ |
| 9978.56 | 0 | 10018.74 | |
| 10027.38 | 0 | 9969.96 | |

levels; and moreover, at my request, he had the very large number of odd levels calculated. The analysis was assisted quite fundamentally by his work. I had been helped in the same way by Shadmi some years ago when analyzing Pd III.

The spectrum Ni II arises from the transitions between the structures $3d^9$, $3d^8\ nx$, $3d^7 4s^2$ and $3d^7\,4s\,4p$. Of these only $3d^9$, $3d^8\,4s$, $3d^8\,4p$ and part of $3d^8\,5s$ were known from my previous analysis. The levels $3d^8(^1S)4s\ ^2S$ and its corresponding $^2P^\circ$ term were lacking and still do not appear to have been found with any certainty in any spectrum. The first necessity of the new analysis was to increase the accuracy of the known levels since all further analysis depends on them. Next followed the discovery of the levels due to the addition of a $5p$ electron to the ground term, $^3F$, of Ni III. On those bases it was then possible to determine higher $d^8\,ns$ members which led to a calculation of a more accurate limit. The series $3d^8(^3F)ns$ was eventually carried to $9s$ and the series based on $^1D$, $^3P$ and $^1G$ to $6s$. Amongst the six components of the $ns$-series there is one oddity of convergence. The $^2F_{3\frac{1}{2}}$, which is above $^4F_{2\frac{1}{2}}$ in $4s$ and $5s$, crosses over so that it is the lower of the two levels from $6s$ on.

The great value of the Shadmi calculations of the even levels was in the prediction of the levels of $3d^7\,4s^2$ comprising $^4F$, $^4P$, $^2PDFGH$ and $^2D$. The predictions led M. C. Diago of the Instituto de Optica in Madrid [6] to the discovery of $^2G$ and $^2H$. Her additional identification of the $^2F$ and the high $^2D$ terms are not confirmed by my more complete results. I have been able to add to the terms $^4F$, $^4P$, $^2D$, $^2F$ and $^2P_{1\frac{1}{2}}$, but the higher $^2D$ term has eluded me as well as the level $^2P_{\frac{1}{2}}$.

The next most important levels to find are those described by $3d^8(^3F)4d$. It was in fact the difficulty of identifying those levels in Cu III which made me turn to Ni II for assistance. With the new very complete list of lines it was possible to identify quite rapidly the 10 levels based on $^3F_4$, nine of the 10 based on $^3F_3$ and eight of the nine on $^3F_2$. Moreover it was possible from intensities to assign reasonable Russell-Saunders names to all the levels. It then appeared that the missing levels were $^2D_{2\frac{1}{2}}$ from $^3F_3$ and $^2D_{1\frac{1}{2}}$ from $^3F_2$. A very broad search for them was unsuccessful. At this point I mentioned the problem to N. Spector during a meeting at the National Bureau of Standards. He was good enough to make a theoretical calculation which surprisingly predicted the positions of the two levels more than 2000 $cm^{-1}$ above the groups to which they belong. The theory of this very curious effect, I must leave to Spector.

Spector's predictions proved very close indeed, the actual levels falling 67 $cm^{-1}$ and 40 $cm^{-1}$, respectively, from the predicted positions. They make the astonishingly large numbers of combinations: 33 for $^2D_{2\frac{1}{2}}$ and 27 for $^2D_{1\frac{1}{2}}$. Spector's calculation included all of the $3d^8\ 4d$ and $3d^8\ 5d$ levels. In the latter configuration I had again failed to find $^2D$ levels, and it is surprising that even with the predictions those levels remain unidentified. For the configuration $3d^8\,6d$ the $^2D_{2\frac{1}{2}}$ level is present in my analysis but not $^2D_{1\frac{1}{2}}$, and the same is true for $7d$. The $3d^8\,8d$ configuration is fragmentary.

In both the $4d$ and $5d$ groups the $^4D$ term departs from the theoretical values by large and irregular amounts. For $4d$ the values of observed-theoretical for the four levels of the $^4D$ term are, respectively, $380, -122, -20, -60$ and for $5d$, $-105, -343, +258, -28$. Although no theoretical values have been calculated for $6d$, $7d$, $8d$, it is obvious from plots of the groups of levels based on the three components of $^3F$ that $^4D_{2\frac{1}{2}}$ and $^4D_{1\frac{1}{2}}$ fluctuate quite widely.

The $4d$-electron levels based on $3d^8\ ^1D$ were all found as were also those from $3d^8\ ^3P$. In the $5d$-group, all but one based on $^1D$ have been identified but four levels based on $^3P$ are missing.

The identification of the numerous levels produced by the addition of an $s$, $p$, or $d$-electron to the $3d^8$ ion left unclassified a very large number of lines throughout the spectrum. Certain strong groups were obviously due to transitions such as $4d-nf$ and $4f-ng$. The $4d-4f$ group was analyzed empirically and later compared with Shadmi's calculations. The groups of $5f$, $6f$ and $7f$-levels were found but with decreasing completeness. The $5g$ levels from $^3F$ were found from a strong group of lines around 9000 Å, but none of the three groups based on the components of the parent term is complete. The $6g$ structure from $^3F_4$ is nearly complete but very few of the levels from $^3F_3$ and $^3F_2$ have been found. The $7g$ structure is represented by only 5 levels.

As I mentioned above, I got essential assistance from Shadmi's computer analysis of all the odd levels due to $3d^8\,4p$, $3d^8\,5p$, $3d^7\,4s\,4p$ as a group. For the calculation of the last structure, it was necessary to assume some particular form of coupling. Shadmi chose the type which can be written $3d^7(X)4s\,4p(^3P$ or $^1P)$ where X stands for any one of the terms of $3d^7$. Shadmi also calculated the configuration $3d^8\,4f$ independently, by assuming that it would not be perturbed by the other odd configurations. The assumption does not seem to be entirely warranted.

In the main calculation Shadmi was able to give origins and Russell-Saunders names to the great majority of the terms and the remainder can be logically assigned, from their positions, as belonging in the main to definite structures.

Shadmi's table lists the terms, not the levels, in order of increasing energy, and for identification I have adopted a nomenclature based on the very old recommendation made by Russell, Shenstone and Turner in 1929 [7]. For example, there are six $^4F^\circ$ terms from $3d^7\,4s\,4p$ which I have serially lettered $z$, $y$, $x$, $w$, $v$, $u$ [8]. Not all the calculated terms are within range of the hollow cathode source in which the maximum energy of excitation by collisions of the second kind is at 136,731 $cm^{-1}$. A few levels are observed above that point, excited either by direct electron bombardment or by excitation of atoms in levels above the lowest point. From the table of calculated terms, it appears that 170 levels of the $3d^7\,4s\,4p$ configuration should be within range. Only 93 have been identified, leaving 77

still to be found. Tables II and III list all of the even and odd levels which have been discovered. The nomenclature for the levels based on $3d^8$ follows that used in "Atomic Energy Levels" [1].

The search for odd levels was assisted by the fact that the excitation in the hollow cathode restricts the range of wave numbers in which combinations of any particular level may be found. By assuming that energy is available up to 137,000 $cm^{-1}$, it is obvious that all lines higher than 128,000 $cm^{-1}$ must be due to $3d\,^2D$. The successive terms come in at decreasing energies so that, for instance, $s^2\,^2F$ cannot have combinations in which it is the lower level, greater then about 44,500 $cm^{-1}$. In point of fact, most even levels come into operation at about 2,000 $cm^{-1}$ less than their possible limit. The odd levels appear as initial levels in a combination at, on the average, only about 200 $cm^{-1}$ below the calculated points. A few odd levels appear at wave numbers higher than the calculated ones, indicating that high even levels may appear at energies above those strictly due to collisions of the second kind.

## TABLE II. Ni II *Even levels (1970)*

| Configuration | Name | Level Observed | Level Computed | O–C |
|---|---|---|---|---|
| $3d^9$ | $3d\ ^2D_{2½}$ | 0.00 | 053 | −53 |
| $3d^9$ | $3d\ ^2D_{1½}$ | 1506.94 | 1581 | −74 |
| $3d^8(^3F)4s$ | $4s\ ^4F_{4½}$ | 8393.90 | 8323 | +71 |
| $3d^8(^3F)4s$ | $4s\ ^4F_{3½}$ | 9330.04 | 9261 | +69 |
| $3d^8(^3F)4s$ | $4s\ ^4F_{2½}$ | 10115.66 | 10055 | +61 |
| $3d^8(^3F)4s$ | $4s\ ^4F_{1½}$ | 10663.89 | 10613 | +51 |
| $3d^8(^3F)4s$ | $4s\ ^2F_{3½}$ | 13550.39 | 13486 | +64 |
| $3d^8(^3F)4s$ | $4s\ ^2F_{2½}$ | 14995.57 | 14960 | +36 |
| $3d^8(^1D)4s$ | $4s'\ ^2D_{2½}$ | 23108.28 | 23103 | +5 |
| $3d^8(^1D)4s$ | $4s'\ ^2D_{1½}$ | 23796.18 | 23774 | +22 |
| $3d^8(^3P)4s$ | $4s''\ ^4P_{1½}$ | 24788.20 | 24754 | +34 |
| $3d^8(^3P)4s$ | $4s''\ ^4P_{0½}$ | 24835.93 | 24779 | +57 |
| $3d^8(^3P)4s$ | $4s''\ ^4P_{2½}$ | 25036.38 | 25062 | −26 |
| $3d^8(^3P)4s$ | $4s''\ ^2P_{1½}$ | 29070.93 | 28959 | +112 |
| $3d^8(^3P)4s$ | $4s''\ ^2P_{0½}$ | 29593.46 | 29433 | +160 |
| $3d^8(^1G)4s$ | $4s'''\ ^2G_{4½}$ | 32499.53 | 32510 | −10 |
| $3d^8(^1G)4s$ | $4s'''\ ^2G_{3½}$ | 32523.54 | 32514 | +10 |
| $3d^8(^1S)4s$ | $4s^{IV}\ ^2S_{0½}$ | | 61473 | |
| $3d^7\,4s^2$ | $s^2\ ^4F_{4½}$ | 51045.46 | 51079 | −34 |
| $3d^7\,4s$ | $s^2\ ^4F_{3½}$ | 52205.95 | 52224 | −18 |
| $3d^7\,4s$ | $s^2\ ^4F_{2½}$ | 53037.93 | 53053 | −15 |
| $3d^7\,4s$ | $s^2\ ^4F_{1½}$ | 53601.19 | 53616 | −15 |
| $3d^7\,4s$ | $s^2\ ^4P_{2½}$ | 67880.16 | 67980 | −100 |
| $3d^7\,4s$ | $s^2\ ^4P_{1½}$ | 68156.57 | 68265 | −108 |
| $3d^7\,4s$ | $s^2\ ^4P_{0½}$ | 68709.76 | 68863 | −153 |
| $3d^7\,4s$ | $s^2\ ^2G_{4½}$ | 70358.94 | 70386 | −27 |
| $3d^7\,4s$ | $s^2\ ^2G_{3½}$ | 71457.74 | 71493 | −35 |
| $3d^7\,4s$ | $s^2\ ^2P_{1½}$ | 73893.73 | 73791 | +103 |
| $3d^7\,4s$ | $s^2\ ^2P_{0½}$ | | 74775 | |
| $3d^7\,4s$ | $s^2\ ^2H_{5½}$ | 76727.36 | 76805 | −78 |
| $3d^7\,4s$ | $s^2\ ^2D_{2½}$ | 77332.47 | 77444 | −112 |
| $3d^7\,4s$ | $s^2\ ^2H_{4½}$ | 77736.79 | 77805 | −68 |
| $3d^7\,4s$ | $s^2\ ^2D_{1½}$ | 78955.45 | 79039 | −84 |
| $3d^8(^3F_4)4s$ | $5s\ ^4F_{4½}$ | 91800.05 | | |
| $3d^8(^3F_4)5s$ | $5s\ ^4F_{3½}$ | 92325.85 | | |
| $3d^7\,4s^2$ | $s^2\ ^2F_{2½}$ | 92373.45 | 92392 | −19 |
| $3d^7\,4s^2$ | $s^2\ ^2F_{3½}$ | 92792.08 | 92888 | −96 |
| $3d^8(^3F_3)5s$ | $5s\ ^4F_{2½}$ | 93390.06 | | |
| $3d^8(^3F_3)5s$ | $5s\ ^2F_{3½}$ | 93528.44 | | |
| $3d^8(^3F_2)5s$ | $5s\ ^4F_{1½}$ | 94067.14 | | |
| $3d^8(^3F_2)5s$ | $5s\ ^2F_{2½}$ | 94729.25 | | |
| $3d^8(^3F_4)4d$ | $4d\ ^4D_{3½}$ | 98467.25 | 98847 | −380 |
| $3d^8(^3F_4)4d$ | $4d\ ^4P_{2½}$ | 98561.22 | 98567 | −6 |
| $3d^8(^3F_4)4d$ | $4d\ ^4H_{6½}$ | 98822.55 | 98743 | +80 |
| $3d^8(^3F_4)4d$ | $4d\ ^4H_{5½}$ | 98969.44 | 98920 | +49 |
| $3d^8(^3F_4)4d$ | $4d\ ^4P_{1½}$ | 99040.75 | 98942 | +99 |
| $3d^8(^3F_4)4d$ | $4d\ ^4G_{5½}$ | 99132.78 | 99137 | −4 |
| $3d^8(^3F_4)4d$ | $4d\ ^4F_{4½}$ | 99154.81 | 99088 | +67 |
| $3d^8(^3F_4)4d$ | $4d\ ^4F_{3½}$ | 99340.55 | 99185 | +156 |
| $3d^8(^3F_4)4d$ | $4d\ ^4G_{4½}$ | 99442.86 | 99443 | 0 |
| $3d^8(^3F_4)4d$ | $4d\ ^4D_{2½}$ | 99559.33 | 99681 | −122 |
| $3d^8(^3F_3)4d$ | $4d\ ^4P_{0½}$ | 100010.17 | 100130 | −120 |
| $3d^8(^3F_3)4d$ | $4d\ ^2P_{1½}$ | 100078.78 | 100134 | −55 |
| $3d^8(^3F_3)4d$ | $4d\ ^2H_{5½}$ | 100309.29 | 100241 | +68 |
| $3d^8(^3F_3)4d$ | $4d\ ^4H_{4½}$ | 100332.09 | 100327 | +5 |
| $3d^8(^3F_3)4d$ | $4d\ ^4F_{2½}$ | 100389.52 | 100358 | +32 |
| $3d^8(^3F_3)4d$ | $4d\ ^2F_{3½}$ | 100475.82 | 100580 | −104 |
| $3d^8(^3F_3)4d$ | $4d\ ^4D_{1½}$ | 100490.95 | 100511 | −20 |
| $3d^8(^3F_3)4d$ | $4d\ ^4G_{3½}$ | 100592.98 | 100451 | +142 |
| $3d^8(^3F_3)4d$ | $4d\ ^2G_{4½}$ | 100619.26 | 100623 | −4 |
| $3d^8(^3F_2)4d$ | $4d\ ^4D_{0½}$ | 100845.41 | 100905 | −60 |
| $3d^8(^3F_2)4d$ | $4d\ ^4H_{3½}$ | 101144.63 | 101171 | −26 |
| $3d^8(^3F_2)4d$ | $4d\ ^2P_{0½}$ | 101246.16 | 101192 | +54 |
| $3d^8(^3F_2)4d$ | $4d\ ^2F_{2½}$ | 101247.37 | 101138 | +109 |
| $3d^8(^3F_2)4d$ | $4d\ ^4F_{1½}$ | 101258.01 | 101245 | +13 |
| $3d^8(^3F_2)4d$ | $4d\ ^2H_{4½}$ | 101357.20 | 101300 | +57 |
| $3d^8(^3F_2)4d$ | $4d\ ^4G_{2½}$ | 101366.14 | 101432 | −66 |
| $3d^8(^3F_2)4d$ | $4d\ ^2G_{3½}$ | 101740.27 | 101807 | −67 |
| $3d^8(^3F_3)4d$ | $4d\ ^2D_{2½}$ | 103025.58 | 102958 | +68 |
| $3d^8(^3F_2)4d$ | $4d\ ^2D_{1½}$ | 103663.50 | 103623 | +41 |
| $3d^8(^1D)5s$ | $5s'\ ^2D_{2½}$ | 106007.89 | | |
| $3d^8(^1D)5s$ | $5s'\ ^2D_{1½}$ | 106133.14 | | |



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TABLE II. Ni II *Even levels (1970)*—Continued

| Configuration | Name | Level Observed | Level Computed | O–C |
|---|---|---|---|---|
| $3d^8(^3P)5s$ | $5s''\ ^4P_{2\frac{1}{2}}$ | 108368.05 | | |
| $3d^8(^3P)5s$ | $5s''\ ^4P_{1\frac{1}{2}}$ | 108548.61 | | |
| $3d^8(^3P)5s$ | $5s''\ ^4P_{0\frac{1}{2}}$ | 108763.32 | | |
| $3d^8(^3P)5s$ | $5s''\ ^2P_{1\frac{1}{2}}$ | 109269.83 | | |
| $3d^8(^3P)5s$ | $5s''\ ^2P_{0\frac{1}{2}}$ | 109675.72 | | |
| $3d^8(^1D)4d$ | $4d'\ ^2F_{2\frac{1}{2}}$ | 112686.30 | 112700 | −14 |
| $3d^8(^1D)4d$ | $4d'\ ^2F_{3\frac{1}{2}}$ | 112719.75 | 112666 | +54 |
| $3d^8(^1D)4d$ | $4d'\ ^2D_{1\frac{1}{2}}$ | 112906.93 | 113087 | −180 |
| $3d^8(^1D)4d$ | $4d'\ ^2G_{4\frac{1}{2}}$ | 113172.96 | 113119 | +54 |
| $3d^8(^1D)4d$ | $4d'\ ^2G_{3\frac{1}{2}}$ | 113177.61 | 113155 | +23 |
| $3d^8(^1D)4d$ | $4d'\ ^2P_{0\frac{1}{2}}$ | 113225.06 | 113116 | +109 |
| $3d^8(^1D)4d$ | $4d'\ ^2D_{2\frac{1}{2}}$ | 113407.31 | 113488 | −81 |
| $3d^8(^1D)4d$ | $4d'\ ^2P_{1\frac{1}{2}}$ | 113408.71 | 113308 | +101 |
| $3d^8(^1D)4d$ | $4d'\ ^2S_{0\frac{1}{2}}$ | 113623.10 | 113716 | −93 |
| $3d^8(^3P)4d$ | $4d''\ ^4D_{3\frac{1}{2}}$ | 114836.63 | 114782 | +55 |
| $3d^8(^3P)4d$ | $4d''\ ^4D_{2\frac{1}{2}}$ | 114874.88 | 114924 | −49 |
| $3d^8(^3P)4d$ | $4d''\ ^4D_{1\frac{1}{2}}$ | 114942.42 | 114927 | +15 |
| $3d^8(^3P)4d$ | $4d''\ ^4D_{0\frac{1}{2}}$ | 114970.19 | 114892 | +78 |
| $3d^8(^1G)5s$ | $5s'''\ ^2G_{4\frac{1}{2}}$ | 115081.36 | | |
| $3d^8(^1G)5s$ | $5s'''\ ^2G_{3\frac{1}{2}}$ | 115085.36 | | |
| $3d^8(^3P)4d$ | $4d''\ ^4F_{4\frac{1}{2}}$ | 115739.15 | 115728 | +11 |
| $3d^8(^3P)4d$ | $4d''\ ^4F_{3\frac{1}{2}}$ | 115827.12 | 115814 | +13 |
| $3d^8(^3P)4d$ | $4d''\ ^2D_{2\frac{1}{2}}$ | 115870.28 | 115960 | −90 |
| $3d^8(^3P)4d$ | $4d''\ ^4F_{2\frac{1}{2}}$ | 115956.71 | 115843 | +114 |
| $3d^8(^3P)4d$ | $4d''\ ^2F_{3\frac{1}{2}}$ | 116145.69 | 116059 | +87 |
| $3d^8(^3P)4d$ | $4d''\ ^4F_{1\frac{1}{2}}$ | 116167.76 | 116083 | +85 |
| $3d^8(^3P)4d$ | $4d''\ ^2F_{2\frac{1}{2}}$ | 116191.47 | 116354 | −163 |
| $3d^8(^3P)4d$ | $4d''\ ^4P_{0\frac{1}{2}}$ | 116261.81 | 116314 | −52 |
| $3d^8(^3P)4d$ | $4d''\ ^4P_{1\frac{1}{2}}$ | 116312.34 | 116281 | +31 |
| $3d^8(^3P)4d$ | $4d''\ ^2D_{1\frac{1}{2}}?$ | 116468.40 | 116623 | −155 |
| $3d^8(^3P)4d$ | $4d''\ ^4P_{2\frac{1}{2}}$ | 116732.51 | 116622 | +111 |
| $3d^8(^3P)4d$ | $4d''\ ^2P_{0\frac{1}{2}}$ | 116786.42 | 116815 | −29 |
| $3d^8(^3F_4)6s$ | $6s\ ^4F_{4\frac{1}{2}}$ | 116833.15 | | |
| $3d^8(^3P)4d$ | $4d''\ ^2P_{1\frac{1}{2}}$ | 116838.33 | 116891 | −53 |
| $3d^8(^3F_4)6s$ | $6s\ ^4F_{3\frac{1}{2}}$ | 117074.70 | | |
| $3d^8(^3F_3)6s$ | $6s\ ^2F_{3\frac{1}{2}}$ | 118294.17 | | |
| $3d^8(^3F_3)6s$ | $6s\ ^4F_{2\frac{1}{2}}$ | 118314.82 | | |
| $3d^8(^3F_2)6s$ | $6s\ ^4F_{1\frac{1}{2}}$ | 119100.06 | | |
| $3d^8(^3F_2)6s$ | $6s\ ^2F_{2\frac{1}{2}}$ | 119315.44 | | |
| $3d^8(^3F_4)5d$ | $5d\ ^4D_{3\frac{1}{2}}$ | 119656.25 | 119761 | −105 |
| $3d^8(^3F_4)5d$ | $5d\ ^4P_{2\frac{1}{2}}$ | 119665.29 | 119641 | +24 |
| $3d^8(^3F_4)5d$ | $5d\ ^4H_{6\frac{1}{2}}$ | 119773.60 | 119709 | +65 |
| $3d^8(^3F_4)5d$ | $5d\ ^4H_{5\frac{1}{2}}$ | 119833.00 | 119840 | −7 |
| $3d^8(^3F_4)5d$ | $5d\ ^4G_{5\frac{1}{2}}$ | 119889.47 | 119852 | +37 |
| $3d^8(^3F_4)5d$ | $5d\ ^4P_{1\frac{1}{2}}$ | 119909.72 | 119911 | −1 |
| $3d^8(^3F_4)5d$ | $5d\ ^4F_{4\frac{1}{2}}$ | 119913.33 | 119859 | +54 |
| $3d^8(^3F_4)5d$ | $5d\ ^4F_{3\frac{1}{2}}$ | 120002.86 | 119919 | +84 |
| $3d^8(^3F_4)5d$ | $5d\ ^4G_{4\frac{1}{2}}$ | 120044.95 | 120092 | −47 |
| $3d^8(^3F_4)5d$ | $5d\ ^4D_{2\frac{1}{2}}$ | 120144.17 | 120487 | −343 |
| $3d^8(^3F_3)5d$ | $5d\ ^4P_{0\frac{1}{2}}$ | 121111.90 | 121137 | −25 |
| $3d^8(^3F_3)5d$ | $5d\ ^2P_{1\frac{1}{2}}$ | 121115.59 | 121135 | −19 |
| $3d^8(^3F_3)5d$ | $5d\ ^2H_{5\frac{1}{2}}$ | 121180.55 | 121139 | +42 |
| $3d^8(^3F_3)5d$ | $5d\ ^4H_{4\frac{1}{2}}$ | 121190.34 | 121188 | +2 |
| $3d^8(^3F_3)5d$ | $5d\ ^4F_{2\frac{1}{2}}$ | 121227.80 | 121185 | +43 |
| $3d^8(^3F_3)5d$ | $5d\ ^2F_{3\frac{1}{2}}$ | 121240.90 | 121341 | −100 |
| $3d^8(^3F_3)5d$ | $5d\ ^2G_{4\frac{1}{2}}$ | 121294.67 | 121326 | −31 |
| $3d^8(^3F_3)5d$ | $5d\ ^4G_{3\frac{1}{2}}$ | 121317.89 | 121233 | +85 |
| $3d^8(^1G)4d$ | $4d'''\ ^2I_{5\frac{1}{2}}$ | 121437.68 | 121350 | +88 |
| $3d^8(^1G)4d$ | $4d'''\ ^2I_{6\frac{1}{2}}$ | 121476.56 | 121350 | +127 |
| $3d^8(^3F_3)5d$ | $5d\ ^4D_{1\frac{1}{2}}$ | 121699.02 | 121441 | +258 |
| $3d^8(^3F_2)5d$ | $5d\ ^4D_{0\frac{1}{2}}$ | 121925.16 | 121953 | −28 |
| $3d^8(^3F_2)5d$ | $5d\ ^4H_{3\frac{1}{2}}$ | 122047.29 | 122049 | −2 |
| $3d^8(^1G)4d$ | $4d'''\ ^2F_{2\frac{1}{2}}$ | 122080.25 | 122038 | +42 |
| $3d^8(^3F_2)5d$ | $5d\ ^4F_{1\frac{1}{2}}$ | 122084.79 | 122090 | −5 |
| $3d^8(^1G)4d$ | $4d'''\ ^2F_{3\frac{1}{2}}$ | 122086.58 | 122040 | +47 |
| $3d^8(^3F_2)5d$ | $5d\ ^2P_{0\frac{1}{2}}$ | 122112.94? | 122135 | −22 |
| $3d^8(^3F_2)5d$ | $5d\ ^2H_{4\frac{1}{2}}$ | 122140.71 | 122127 | +14 |
| $3d^8(^3F_2)5d$ | $5d\ ^4G_{2\frac{1}{2}}$ | 122144.99 | 122169 | −24 |
| $3d^8(^3F_2)5d$ | $5d\ ^2F_{2\frac{1}{2}}$ | 122175.42? | 121844 | +331 |
| $3d^8(^3F_2)5d$ | $5d\ ^2G_{3\frac{1}{2}}$ | 122270.05 | 122378 | −108 |
| $3d^8(^1G)4d$ | $4d'''\ ^2H_{4\frac{1}{2}}$ | 122790.41 | 122846 | −56 |
| $3d^8(^1G)4d$ | $4d'''\ ^2H_{5\frac{1}{2}}$ | 122821.63 | 122844 | −22 |

TABLE II. Ni II *Even levels (1970)*—Continued

| Configuration | Name | Level Observed | Level Computed | O–C | Configuration | Name | Level Observed | Level Computed | O–C |
|---|---|---|---|---|---|---|---|---|---|
| $3d^8(^1G)4d$ | $4d'''\ ^2G_{4½}$ | 122837.33 | 123012 | −175 | $3d^8(^3F_3)5g$ | $5g\ ^4G_{3½}$ | 130320.94 | | |
| $3d^8(^1G)4d$ | $4d'''\ ^2G_{3½}$ | 122847.60 | 123005 | −157 | $3d^8(^3F_3)5g$ | $5g\ ^2H_{5½}$ | 130321.74 | | |
| $3d^8(^3F_4)7s$ | $7s\ ^4F_{4½}$ | 127867.13 | | | $3d^8(^3F_3)5g$ | $5g\ ^2G_{4½}$ | 130324.71 | | |
| $3d^8(^3F_4)7s$ | $7s\ ^4F_{3½}$ | 127991.56 | | | $3d^8(^3F_3)6d$ | $6d\ ^2P_{1½}$ | 130691.35 | | |
| $3d^8(^3F_4)5g$ | $5g\ ^4P_{2½}$ | 128912.81 | | | $3d^8(^3F_3)6d$ | $6d\ ^4P_{0½}$ | 130710.85 | | |
| $3d^8(^3F_4)5d$ | $5g\ ^4I_{7½}$ | 128924.94 | | | $3d^8(^3F_3)6d$ | $6d\ ^4F_{2½}$ | 130730.53 | | |
| $3d^8(^3F_4)5d$ | $5g\ ^4I_{6½}$ | 128924.94 | | | $3d^8(^3F_3)6d$ | $6d\ ^2H_{5½}$ | 130751.03 | | |
| $3d^8(^3F_4)5d$ | $5g\ ^4P_{1½}$ | 128939.74 | | | $3d^8(^3F_3)6d$ | $6d\ ^4H_{4½}$ | 130757.51 | | |
| $3d^8(^3F_4)5d$ | $5g\ ^4D_{2½}$ | 128944.31 | | | $3d^8(^3F_3)6d$ | $6d\ ^2F_{3½}$ | 130765.26 | | |
| $3d^8(^3F_4)5d$ | $5g\ ^4K_{7½}$ | 128946.15 | | | $3d^8(^3F_3)6d$ | $6d\ ^2G_{4½}$ | 130801.33 | | |
| $3d^8(^3F_4)5d$ | $5g\ ^4K_{8½}$ | 128946.22 | | | $3d^8(^3F_3)6d$ | $6d\ ^4G_{3½}$ | 130815.91 | | |
| $3d^8(^3F_4)5d$ | $5g\ ^4D_{3½}$ | 128950.87 | | | $3d^8(^1D)6s$ | $6s'\ ^2D_{2½}$ | 130900.65 | | |
| $3d^8(^3F_4)5d$ | $5g\ ^4F_{3½}$ | 128958.37 | | | $3d^8(^3F_3)6d$ | $6d\ ^4D_{1½}$ | 130942.30 | | |
| $3d^8(^3F_4)5d$ | $5g\ ^4H_{5½}$ | 128960.74 | | | $3d^8(^1D)6s$ | $6s'\ ^2D_{1½}$ | 130942.36 | | |
| $3d^8(^3F_4)5d$ | $5g\ ^4H_{6½}$ | 128960.74 | | | $3d^8(^3F_3)6d$ | $6d\ ^2D_{2½}$ | 131032.01 | | |
| $3d^8(^3F_4)5d$ | $5g\ ^4F_{4½}$ | 128964.63 | | | $3d^8(^3F_2)5g$ | $5g\ ^2K_{8½}$ | 131218.55? | | |
| $3d^8(^3F_4)5d$ | $5g\ ^4G_{5½}$ | 128966.52 | | | $3d^8(^3F_2)5g$ | $5g\ ^2G_{3½}$ | 131221.09? | | |
| $3d^8(^3F_4)5d$ | $5g\ ^4G_{4½}$ | 128966.52 | | | $3d^8(^3F_2)5g$ | $5g\ ^4F_{1½}$ | 131222.97 | | |
| $3d^8(^3F_3)7s$ | $7s\ ^2F_{3½}$ | 129271.72 | | | $3d^8(^3F_2)5g$ | $5g\ ^2F_{2½}$ | 131223.02 | | |
| $3d^8(^3F_4)6d$ | $6d\ ^4P_{2½}$ | 129284.50 | | | $3d^8(^3F_2)5g$ | $5g\ ^4H_{3½}$ | 131233.28? | | |
| $3d^8(^3F_3)7s$ | $7s\ ^4F_{2½}$ | 129294.51 | | | $3d^8(^3F_2)5g$ | $5g\ ^2H_{4½}$ | 131233.32 | | |
| $3d^8(^3F_4)6d$ | $6d\ ^4D_{3½}$ | 129297.91 | | | $3d^8(^3F_2)6d$ | $6d\ ^4F_{1½}$ | 131620.45 | | |
| $3d^8(^3F_4)6d$ | $6d\ ^4H_{6½}$ | 129367.91 | | | $3d^8(^3F_2)6d$ | $6d\ ^4H_{3½}$ | 131637.10 | | |
| $3d^8(^3F_4)6d$ | $6d\ ^4H_{5½}$ | 129396.04 | | | $3d^8(^3F_2)6d$ | $6d\ ^2P_{0½}$ | 131655.83 | | |
| $3d^8(^3F_4)6d$ | $6d\ ^4F_{4½}$ | 129419.58 | | | $3d^8(^3F_2)6d$ | $6d\ ^4G_{2½}$ | 131670.87 | | |
| $3d^8(^3F_4)6d$ | $6d\ ^4G_{5½}$ | 129424.03 | | | $3d^8(^3F_2)6d$ | $6d\ ^2H_{4½}$ | 131686.56 | | |
| $3d^8(^3F_4)6d$ | $6d\ ^4F_{3½}$ | 129474.27 | | | $3d^8(^3F_2)6d$ | $6d\ ^2G_{3½}$ | 131750.73 | | |
| $3d^8(^3F_4)6d$ | $6d\ ^4P_{1½}$ | 129479.73 | | | $3d^8(^3F_2)6d$ | $6d\ ^2F_{2½}$ | 131796.26 | | |
| $3d^8(^3F_4)6d$ | $6d\ ^4G_{4½}$ | 129503.24 | | | $3d^8(^3P)6s$ | $6s''\ ^4P_{2½}$ | 133443.89 | | |
| $3d^8(^3F_4)6d$ | $6d\ ^4D_{2½}$ | 129842.33 | | | $3d^8(^3P)6s$ | $6s''\ ^4P_{1½}$ | 133613.99 | | |
| $3d^8(^3F_2)7s$ | $7s\ ^4F_{1½}$ | 130135.19 | | | $3d^8(^3F_4)8s$ | $8s\ ^4F_{4½}$ | 133715.13 | | |
| $3d^8(^3F_2)7s$ | $7s\ ^2F_{2½}$ | 130236.26 | | | $3d^8(^1D)5d$ | $5d'\ ^2F_{3½}$ | 133734.98 | 133690 | +45 |
| $3d^8(^3F_3)5g$ | $5g\ ^4K_{6½}$ | 130301.80? | | | $3d^8(^1D)5d$ | $5d'\ ^2F_{2½}$ | 133735.26 | 133695 | +40 |
| $3d^8(^3F_3)5g$ | $5g\ ^2K_{7½}$ | 130311.33 | | | $3d^8(^3F_4)8s$ | $8s\ ^4F_{3½}$ | 133809.76 | | |
| $3d^8(^3F_3)5g$ | $5g\ ^4I_{5½}$ | 130313.51 | | | $3d^8(^3P)6s$ | $6s''\ ^4P_{0½}$ | 133857.73 | | |
| $3d^8(^3F_3)5g$ | $5g\ ^4F_{2½}$ | 130314.07 | | | $3d^8(^3P)6s$ | $6s''\ ^2P_{1½}$ | 133862.21 | | |

TABLE II. Ni II *Even levels (1970)*—Continued

| Configuration | Name | Level Observed | Level Computed | O–C |
|---|---|---|---|---|
| $3d^8(^1D)5d$ | $5d'\ ^2D_{1\frac{1}{2}}$ | 133903.00 | 133911 | −8 |
| $3d^8(^1D)5d$ | $5d'\ ^2G_{4\frac{1}{2}}$ | 133922.91 | 133842 | +71 |
| $3d^8(^1D)5d$ | $5d'\ ^2G_{3\frac{1}{2}}$ | 133929.88 | 133862 | +68 |
| $3d^8(^1D)5d$ | $5d'\ ^2P_{0\frac{1}{2}}$ | 133954.85 | 133838 | +117 |
| $3d^8(^1D)5d$ | $5d'\ ^2D_{2\frac{1}{2}}$ | 134053.05 | 134196 | −143 |
| $3d^8(^1D)5d$ | $5d'\ ^2P_{1\frac{1}{2}}$ | 134067.76 | 133980 | +88 |
| $3d^8(^3P)6s$ | $6s''\ ^2P_{0\frac{1}{2}}$ | 134241.96 | | |
| $3d^8(^3F_4)6g$ | $6g\ ^4I_{7\frac{1}{2}}$ | 134316.80 | | |
| $3d^8(^3F_4)6g$ | $6g\ ^4I_{6\frac{1}{2}}$ | 134316.85 | | |
| $3d^8(^3F_4)6g$ | $6g\ ^4P_{2\frac{1}{2}}$ | 134323.88 | | |
| $3d^8(^3F_4)6g$ | $6g\ ^4P_{1\frac{1}{2}}$ | 134323.88 | | |
| $3d^8(^3F_4)6g$ | $6g\ ^4K_{8\frac{1}{2}}$ | 134325.15 | | |
| $3d^8(^3F_4)6g$ | $6g\ ^4K_{7\frac{1}{2}}$ | 134325.15 | | |
| $3d^8(^3F_4)6g$ | $6g\ ^4D_{3\frac{1}{2}}$ | 134327.54 | | |
| $3d^8(^3F_4)6g$ | $6g\ ^4D_{2\frac{1}{2}}$ | 134327.61 | | |
| $3d^8(^3F_4)6g$ | $6g\ ^4F_{4\frac{1}{2}}$ | 134331.84 | | |
| $3d^8(^3F_4)6g$ | $6g\ ^4F_{3\frac{1}{2}}$ | 134331.89 | | |
| $3d^8(^3F_4)6g$ | $6g\ ^4H_{6\frac{1}{2}}$ | 134333.41 | | |
| $3d^8(^3F_4)6g$ | $6g\ ^4H_{5\frac{1}{2}}$ | 134333.41 | | |
| $3d^8(^3F_4)7d$ | $6g\ ^4D_{1\frac{1}{2}}$ | 134334.46? | | |
| $3d^8(^3F_4)7d$ | $6g\ ^4G_{5\frac{1}{2}}$ | 134336.68 | | |
| $3d^8(^3F_4)7d$ | $6g\ ^4G_{4\frac{1}{2}}$ | 134336.68 | | |
| $3d^8(^3F_4)7d$ | $7d\ ^4D_{3\frac{1}{2}}$ | 134527.24 | | |
| $3d^8(^3F_4)7d$ | $7d\ ^4P_{2\frac{1}{2}}$ | 134539.37 | | |
| $3d^8(^3F_4)7d$ | $7d\ ^4H_{6\frac{1}{2}}$ | 134583.07 | | |
| $3d^8(^3F_4)7d$ | $7d\ ^4H_{5\frac{1}{2}}$ | 134597.43 | | |
| $3d^8(^3F_4)7d$ | $7d\ ^4F_{4\frac{1}{2}}$ | 134607.37 | | |
| $3d^8(^3F_4)7d$ | $7d\ ^4G_{5\frac{1}{2}}$ | 134614.55 | | |
| $3d^8(^3F_4)7d$ | $7d\ ^4F_{3\frac{1}{2}}$ | 134642.09 | | |
| $3d^8(^3F_4)7d$ | $7d\ ^4G_{4\frac{1}{2}}$ | 134658.60 | | |
| $3d^8(^3F_4)7d$ | $7d\ ^4P_{1\frac{1}{2}}$ | 134670.07 | | |
| $3d^8(^3F_4)7d$ | $7d\ ^4D_{2\frac{1}{2}}$ | 134978.47 | | |
| $3d^8(^3F_3)8s$ | $8s\ ^2F_{3\frac{1}{2}}$ | 135100.45 | | |
| $3d^8(^3F_3)8s$ | $8s\ ^4F_{2\frac{1}{2}}$ | 135116.72 | | |
| $3d^8(^3F_3)6g$ | $6g\ ^2I_{6\frac{1}{2}}$ | 135678.18? | | |
| $3d^8(^3F_3)6g$ | $6g\ ^2K_{7\frac{1}{2}}$ | 135686.64 | | |
| $3d^8(^3F_3)6g$ | $6g\ ^4K_{6\frac{1}{2}}$ | 135686.64 | | |
| $3d^8(^3F_3)6g$ | $6g\ ^2F_{3\frac{1}{2}}$ | 135693.43 | | |
| $3d^8(^3F_3)6g$ | $6g\ ^4F_{2\frac{1}{2}}$ | 135693.43 | | |
| $3d^8(^3F_3)6g$ | $6g\ ^2H_{5\frac{1}{2}}$ | 135693.57 | | |
| $3d^8(^3F_3)6g$ | $6g\ ^4H_{4\frac{1}{2}}$? | 135693.57? | | |
| $3d^8(^3F_3)6g$ | $6g\ ^2G_{4\frac{1}{2}}$ | 135695.67 | | |
| $3d^8(^3F_3)7d$ | $7d\ ^4F_{2\frac{1}{2}}$ | 135901.96 | | |
| $3d^8(^3F_3)7d$ | $7d\ ^2F_{3\frac{1}{2}}$ | 135944.40 | | |
| $3d^8(^3F_3)7d$ | $7d\ ^2H_{5\frac{1}{2}}$ | 135956.01 | | |
| $3d^8(^3F_3)7d$ | $7d\ ^4H_{4\frac{1}{2}}$ | 135960.08 | | |
| $3d^8(^3F_3)7d$ | $7d\ ^2G_{4\frac{1}{2}}$ | 135977.31 | | |
| $3d^8(^3F_2)8s$ | $8s\ ^4F_{1\frac{1}{2}}$ | 135983.22 | | |
| $3d^8(^3F_3)7d$ | $7d\ ^4G_{3\frac{1}{2}}$ | 135986.06 | | |
| $3d^8(^3F_3)7d$ | $7d\ ^2D_{2\frac{1}{2}}$ | 135031.43 | | |
| $3d^8(^3F_2)8s$ | $8s\ ^2F_{2\frac{1}{2}}$ | 136050.53 | | |
| $3d^8(^3F_3)7d$ | $7d\ ^4D_{1\frac{1}{2}}$ | 136054.50 | | |
| $3d^8(^3P)5d$ | $5d''\ ^4D_{3\frac{1}{2}}$ | 136201.46 | 136181 | +20 |
| $3d^8(^3P)5d$ | $5d''\ ^4D_{2\frac{1}{2}}$ | 136288.60 | 136256 | +33 |
| $3d^8(^3P)5d$ | $5d''\ ^4D_{0\frac{1}{2}}$ | 136290.83? | 136289 | +2 |
| $3d^8(^3P)5d$ | $5d''\ ^4D_{1\frac{1}{2}}$ | 136327.55 | 136290 | +38 |
| $3d^8(^3P)5d$ | $5d''\ ^4F_{4\frac{1}{2}}$ | 136519.28 | 136543 | −24 |
| $3d^8(^3P)5d$ | $5d''\ ^4F_{3\frac{1}{2}}$ | 136589.35 | 136643 | −54 |
| $3d^8(^3F_2)6g$ | $6g\ ^2K_{6\frac{1}{2}}$ | 136596.04 | | |
| $3d^8(^3F_2)6g$ | $6g\ ^4K_{5\frac{1}{2}}$ | 136596.04 | | |
| $3d^8(^3F_2)6g$ | $6g\ ^2I_{5\frac{1}{2}}$ | 136598.73? | | |
| $3d^8(^3F_2)6g$ | $6g\ ^2G_{3\frac{1}{2}}$ | 136604.79? | | |
| $3d^8(^3P)5d$ | $5d''\ ^4P_{0\frac{1}{2}}$ | 136725.33 | 136814 | −89 |
| $3d^8(^3P)5d$ | $5d''\ ^4F_{1\frac{1}{2}}$ | 136732.74 | 136927 | −194 |
| $3d^8(^3P)5d$ | $5d''\ ^4F_{2\frac{1}{2}}$ | 136766.49 | 136716 | +50 |
| $3d^8(^3F_2)7d$ | $7d\ ^4F_{1\frac{1}{2}}$ | 136852.44 | | |
| $3d^8(^3F_2)7d$ | $7d\ ^2H_{4\frac{1}{2}}$ | 136880.56 | | |
| $3d^8(^3F_2)7d$ | $7d\ ^4H_{3\frac{1}{2}}$ | 136895.36? | | |
| $3d^8(^3F_2)7d$ | $7d\ ^4G_{2\frac{1}{2}}$ | 136899.34 | | |
| $3d^8(^3P)5d$ | $5d''\ ^4P_{1\frac{1}{2}}$ | 136899.33 | 136827 | +72 |
| $3d^8(^3F_2)7d$ | $7d\ ^2G_{3\frac{1}{2}}$ | 136936.82 | | |
| $3d^8(^3F_2)7d$ | $7d\ ^2P_{0\frac{1}{2}}$ | 136955.28 | | |

TABLE II. Ni II *Even levels (1970)*—Continued

| Configuration | Name | Level Observed | Level Computed | O–C | Configuration | Name | Level Observed | Level Computed | O–C |
|---|---|---|---|---|---|---|---|---|---|
| $3d^8(^3F_2)7d$ | $7d\ ^2F_{2\frac{1}{2}}$ | 136959.86 | | | $3d^8(^3F_4)8d$ | $8d\ ^4F_{4\frac{1}{2}}$ | 137753.87 | | |
| $3d^8(^3P)5d$ | $5d''\ ^4P_{2\frac{1}{2}}$ | 136960.75 | 136909 | + 52 | $3d^8(^3F_4)8d$ | $8d\ ^4G_{5\frac{1}{2}}$ | 137754.78 | | |
| $3d^8(^3F_4)9s$ | $9s\ ^4F_{4\frac{1}{2}}$ | 137188.58 | | | $3d^8(^3F_4)8d$ | $8d\ ^4F_{3\frac{1}{2}}$ | 137776.55 | | |
| $3d^8(^3P)5d$ | $5d''\ ^2P_{0\frac{1}{2}}$ | 137211.93 | 137134 | + 78 | $3d^8(^3F_4)8d$ | $8d\ ^4G_{4\frac{1}{2}}$ | 137782.50? | | |
| $3d^8(^3F_4)9s$ | $9s\ ^4F_{3\frac{1}{2}}$ | 137236.28 | | | $3d^8(^3F_4)8d$ | $8d\ ^4D_{2\frac{1}{2}}$ | 138014.53 | | |
| $3d^8(^3P)5d$ | $5d''\ ^2P_{1\frac{1}{2}}$ | 137278.22? | 137241 | + 37 | $3d^8(^3F_3)9s$ | $9s\ ^2F_{3\frac{1}{2}}$ | 138563.71 | | |
| $3d^8(^3F_4)7g$ | $7g\ ^4K_{8\frac{1}{2}}$ | 137568.02 | | | $3d^8(^3F_3)9s$ | $9s\ ^4F_{2\frac{1}{2}}$ | 138575.69 | | |
| $3d^8(^3F_4)7g$ | $7g\ ^4K_{7\frac{1}{2}}$ | 137568.00 | | | $3d^8(^3F_3)7g$ | $7g\ ^2K_{7\frac{1}{2}}$ | 138928.70 | | |
| $3d^8(^3F_4)7g$ | $7g\ ^4H_{6\frac{1}{2}}$ | 137573.19 | | | $3d^8(^3F_3)8d$ | $8d\ ^2H_{5\frac{1}{2}}$ | 139103.05 | | |
| $3d^8(^3F_4)7g$ | $7g\ ^4H_{5\frac{1}{2}}$ | 137573.19 | | | $3d^8(^3F_2)9s$ | $9s\ ^4F_{1\frac{1}{2}}$ | 139456.75 | | |
| $3d^8(^3F_4)7g$ | $7g\ ^4G_{5\frac{1}{2}}$ | 137575.14? | | | $3d^8(^3F_2)9s$ | $9s\ ^2F_{2\frac{1}{2}}$ | 139492.10 | | |
| $3d^8(^3F_4)8d$ | $8d\ ^4P_{2\frac{1}{2}}$ | 137706.71 | | | $3d^8(^3F_2)7g$ | $7g\ ^2K_{6\frac{1}{2}}$ | 139834.24 | | |
| $3d^8(^3F_4)8d$ | $8d\ ^4D_{3\frac{1}{2}}$ | 137707.26 | | | $3d^8(^1G)6s$ | $6s'''\ ^2G_{4\frac{1}{2}}$ | 140006.17 | | |
| $3d^8(^3F_4)8d$ | $8d\ ^4H_{6\frac{1}{2}}$ | 137735.22 | | | $3d^8(^1G)6s$ | $6s'''\ ^2G_{3\frac{1}{2}}$ | 140008.76 | | |
| $3d^8(^3F_4)8d$ | $8d\ ^4H_{5\frac{1}{2}}$ | 137742.95 | | | $3d^8\ ^3F_4$ (Ni III) | | 146541.56 | | |

## TABLE III. Ni II *Odd levels (1970)*

| Configuration | Name | Level Observed | Level Computed | O–C | Configuration | Name | Level Observed | Level Computed | O–C |
|---|---|---|---|---|---|---|---|---|---|
| $3d^8(^3F)4p$ | $4p\ ^4D^\circ_{3\frac{1}{2}}$ | 51557.85 | 51680 | −122 | $3d^8(^3P)4p$ | $4p''\ ^4S^\circ_{1\frac{1}{2}}$ | 74300.93 | 74297 | +4 |
| $3d^8(^3F)4p$ | $4p\ ^4D^\circ_{2\frac{1}{2}}$ | 52738.45 | 52837 | −99 | $3d^8(^1G)4p$ | $4p'''\ ^2H^\circ_{4\frac{1}{2}}$ | 75149.48 | 75135 | +14 |
| $3d^8(^3F)4p$ | $4p\ ^4G^\circ_{4\frac{1}{2}}$ | 53365.17 | 53351 | +14 | $3d^8(^1G)4p$ | $4p'''\ ^2H^\circ_{5\frac{1}{2}}$ | 75721.68 | 75661 | +61 |
| $3d^8(^3F)4p$ | $4p\ ^4G^\circ_{5\frac{1}{2}}$ | 53496.49 | 53394 | +102 | $3d^8(^1G)4p$ | $4p'''\ ^2F^\circ_{3\frac{1}{2}}$ | 75917.63 | 75942 | −24 |
| $3d^8(^3F)4p$ | $4p\ ^4D^\circ_{1\frac{1}{2}}$ | 53634.62 | 53721 | −86 | $3d^8(^1G)4p$ | $4p'''\ ^2F^\circ_{2\frac{1}{2}}$ | 76402.03 | 76372 | +30 |
| $3d^8(^3F)4p$ | $4p\ ^4D^\circ_{0\frac{1}{2}}$ | 54176.26 | 54258 | −82 | $3d^8(^1G)4p$ | $4p'''\ ^2G^\circ_{3\frac{1}{2}}$ | 79823.03 | 79854 | −31 |
| $3d^8(^3F)4p$ | $4p\ ^4G^\circ_{3\frac{1}{2}}$ | 54262.63 | 54214 | +49 | $3d^8(^1G)4p$ | $4p'''\ ^2G^\circ_{4\frac{1}{2}}$ | 79923.88 | 79959 | −35 |
| $3d^8(^3F)4p$ | $4p\ ^4F^\circ_{4\frac{1}{2}}$ | 54557.05 | 54501 | +56 | $3d^7(^4F)sp(^3P)$ | $z\ ^6F^\circ_{5\frac{1}{2}}$ | 86343.21 | 86612 | −269 |
| $3d^8(^3F)4p$ | $4p\ ^4G^\circ_{2\frac{1}{2}}$ | 55018.71 | 54958 | +61 | $3d^7(^4F)sp(^3P)$ | $z\ ^6F^\circ_{4\frac{1}{2}}$ | 86870.03 | 86978 | −108 |
| $3d^8(^3F)4p$ | $4p\ ^2G^\circ_{4\frac{1}{2}}$ | 55299.65 | 55289 | +11 | $3d^7(^4F)sp(^3P)$ | $z\ ^6F^\circ_{3\frac{1}{2}}$ | 87538.09 | 87608 | −70 |
| $3d^8(^3F)4p$ | $4p\ ^4F^\circ_{3\frac{1}{2}}$ | 55417.83 | 55339 | +79 | $3d^7(^4F)sp(^3P)$ | $z\ ^6F^\circ_{2\frac{1}{2}}$ | 88128.56 | 88163 | −34 |
| $3d^8(^3F)4p$ | $4p\ ^4F^\circ_{2\frac{1}{2}}$ | 56075.26 | 55990 | +85 | $3d^7(^4F)sp(^3P)$ | $z\ ^6D^\circ_{4\frac{1}{2}}$ | 88171.88 | 88263 | −91 |
| $3d^8(^3F)4p$ | $4p\ ^2G^\circ_{3\frac{1}{2}}$ | 56371.41 | 56429 | −58 | $3d^7(^4F)sp(^3P)$ | $z\ ^6F^\circ_{11/2}$ | 88582.01 | 88586 | −4 |
| $3d^8(^3F)4p$ | $4p\ ^4F^\circ_{1\frac{1}{2}}$ | 56424.49 | 56348 | +76 | $3d^7(^4F)sp(^3P)$ | $z\ ^6F^\circ_{0\frac{1}{2}}$ | 88881.59 | 88851 | +31 |
| $3d^8(^3F)4p$ | $4p\ ^2F^\circ_{3\frac{1}{2}}$ | 57080.55 | 57093 | −12 | $3d^7(^4F)sp(^3P)$ | $z\ ^6D^\circ_{3\frac{1}{2}}$ | 89100.49 | 89157 | −57 |
| $3d^8(^3F)4p$ | $4p\ ^2D^\circ_{2\frac{1}{2}}$ | 57420.16 | 57394 | +26 | $3d^7(^4F)sp(^3P)$ | $z\ ^6G^\circ_{5\frac{1}{2}}$ | 89460.35 | 89297 | +163 |
| $3d^8(^3F)4p$ | $4p\ ^2F^\circ_{2\frac{1}{2}}$ | 58493.21 | 58481 | +12 | $3d^7(^4F)sp(^3P)$ | $z\ ^6G^\circ_{4\frac{1}{2}}$ | 89918.47 | 89782 | +136 |
| $3d^8(^3F)4p$ | $4p\ ^2D^\circ_{1\frac{1}{2}}$ | 58705.95 | 58675 | +31 | $3d^7(^4F)sp(^3P)$ | $z\ ^6G^\circ_{3\frac{1}{2}}$ | 90275.30 | 90166 | +109 |
| $3d^8(^3P)4p$ | $4p''\ ^4P^\circ_{2\frac{1}{2}}$ | 66571.34 | 66608 | −37 | $3d^7(^4F)sp(^3P)$ | $z\ ^6G^\circ_{2\frac{1}{2}}$ | 90526.18? | 90446 | +80 |
| $3d^8(^3P)4p$ | $4p''\ ^4P^\circ_{1\frac{1}{2}}$ | 66579.71 | 66606 | −26 | $3d^7(^4F)sp(^3P)$ | $z\ ^4F^\circ_{4\frac{1}{2}}$ | 94283.94 | 94253 | +31 |
| $3d^8(^3P)4p$ | $4p''\ ^4P^\circ_{0\frac{1}{2}}$ | 67031.02 | 67028 | +3 | $3d^7(^4F)sp(^3P)$ | $z\ ^4G^\circ_{5\frac{1}{2}}$ | 94396.74 | 94355 | +42 |
| $3d^8(^1D)4p$ | $4p'\ ^2F^\circ_{2\frac{1}{2}}$ | 67694.64 | 67687 | +8 | $3d^7(^4F)sp(^3P)$ | $z\ ^4F^\circ_{3\frac{1}{2}}$ | 94705.93 | 94704 | +2 |
| $3d^8(^1D)4p$ | $4p'\ ^2F^\circ_{3\frac{1}{2}}$ | 68131.21 | 68086 | +45 | $3d^7(^4F)sp(^3P)$ | $z\ ^4G^\circ_{4\frac{1}{2}}$ | 95017.71 | 94983 | +35 |
| $3d^8(^1D)4p$ | $4p'\ ^2D^\circ_{1\frac{1}{2}}$ | 68154.31 | 68237 | −83 | $3d^7(^4F)sp(^3P)$ | $z\ ^4F^\circ_{2\frac{1}{2}}$ | 95332.53 | 95311 | +22 |
| $3d^8(^1D)4p$ | $4p'\ ^2P^\circ_{0\frac{1}{2}}$ | 68281.62 | 68176 | +106 | $3d^7(^4F)sp(^3P)$ | $z\ ^4G^\circ_{3\frac{1}{2}}$ | 95573.39 | 95583 | −10 |
| $3d^8(^1D)4p$ | $4p'\ ^2D^\circ_{2\frac{1}{2}}$ | 68735.98 | 68816 | −80 | $3d^7(^4F)sp(^3P)$ | $z\ ^4F^\circ_{1\frac{1}{2}}$ | 95893.76 | 95845 | +49 |
| $3d^8(^1D)4p$ | $4p'\ ^2P^\circ_{1\frac{1}{2}}$ | 68965.65 | 68884 | +82 | $3d^7(^4F)sp(^3P)$ | $z\ ^4G^\circ_{2\frac{1}{2}}$ | 96052.48 | 96067 | −15 |
| $3d^8(^3P)4p$ | $4p''\ ^4D^\circ_{2\frac{1}{2}}$ | 70635.46 | 70632 | +3 | $3d^7(^4F)sp(^3P)$ | $z\ ^4D^\circ_{3\frac{1}{2}}$ | 96535.87 | 96627 | −91 |
| $3d^8(^3P)4p$ | $4p''\ ^4D^\circ_{1\frac{1}{2}}$ | 70706.77 | 70678 | +29 | $3d^7(^4F)sp(^3P)$ | $z\ ^4D^\circ_{2\frac{1}{2}}$ | 97273.83 | 97361 | −87 |
| $3d^8(^3P)4p$ | $4p''\ ^4D^\circ_{0\frac{1}{2}}$ | 70748.70 | 70725 | +24 | $3d^7(^4F)sp(^3P)$ | $z\ ^4D^\circ_{1\frac{1}{2}}$ | 97799.66 | 97899 | −99 |
| $3d^8(^3P)4p$ | $4p''\ ^4D^\circ_{3\frac{1}{2}}$ | 70778.12 | 70775 | +3 | $3d^7(^4F)sp(^3P)$ | $z\ ^4D^\circ_{0\frac{1}{2}}$ | 98122.63 | 98231 | −108 |
| $3d^8(^3P)4p$ | $4p''\ ^2D^\circ_{2\frac{1}{2}}$ | 71770.83 | 71860 | −89 | $3d^7(^4F)sp(^3P)$ | $z\ ^2G^\circ_{4\frac{1}{2}}$ | 98276.70 | 98385 | −108 |
| $3d^8(^3P)4p$ | $4p''\ ^2D^\circ_{1\frac{1}{2}}$ | 72375.42 | 72425 | −50 | $3d^7(^4F)sp(^3P)$ | $z\ ^2F^\circ_{3\frac{1}{2}}$ | 99418.61 | 99183 | +236 |
| $3d^8(^3P)4p$ | $4p''\ ^2P^\circ_{1\frac{1}{2}}$ | 72985.65 | 72944 | +42 | $3d^7(^4F)sp(^3P)$ | $z\ ^2G^\circ_{3\frac{1}{2}}$? | 99844.13 | 99908 | −64 |
| $3d^8(^3P)4p$ | $4p''\ ^2P^\circ_{0\frac{1}{2}}$ | 73903.25 | 73887 | +16 | $3d^7(^4F)sp(^3P)$ | $z\ ^2F^\circ_{2\frac{1}{2}}$ | 100609.01 | 100380 | +229 |
| $3d^8(^3P)4p$ | $4p''\ ^2S^\circ_{0\frac{1}{2}}$ | 74283.33 | 74442 | −159 | $3d^7(^4F)sp(^3P)$ | $z\ ^2D^\circ_{2\frac{1}{2}}$ | 101754.80 | 101694 | +61 |

TABLE III. Ni II *Odd levels (1970)*—Continued

| Configuration | Name | | Level Observed | Level Computed | O–C |
|---|---|---|---|---|---|
| $3d^7(^4F)sp(^3P)$ | $z$ | $^2D^\circ_{1\frac{1}{2}}$ | 102742.74 | 102736 | +7 |
| $3d^8(^3F_4)5p$ | $5p$ | $^4D^\circ_{3\frac{1}{2}}$ | 103653.03 | 103735 | −82 |
| $3d^8(^3F_4)5p$ | $5p$ | $^4F^\circ_{4\frac{1}{2}}$ | 104081.04 | 104132 | −51 |
| $3d^8(^3F_4)5p$ | $5p$ | $^4G^\circ_{5\frac{1}{2}}$ | 104147.29 | 104008 | +139 |
| $3d^8(^3F_4)5p$ | $5p$ | $^4G^\circ_{4\frac{1}{2}}$ | 104298.23 | 104344 | −46 |
| $3d^8(^3F_4)5p$ | $5p$ | $^4D^\circ_{2\frac{1}{2}}$ | 104503.22 | 104531 | −28 |
| $3d^8(^3F_4)5p$ | $5p$ | $^4F^\circ_{3\frac{1}{2}}$ | 104646.52 | 104673 | −26 |
| $3d^8(^3F_3)5p$ | $5p$ | $^4D^\circ_{1\frac{1}{2}}$ | 105439.85 | 105464 | −24 |
| $3d^8(^3F_3)5p$ | $5p$ | $^4G^\circ_{3\frac{1}{2}}$ | 105499.05 | 105480 | +19 |
| $3d^8(^3F_3)5p$ | $5p$ | $^2G^\circ_{4\frac{1}{2}}$ | 105588.89 | 105539 | +50 |
| $3d^8(^3F_3)5p$ | $5p$ | $^4F^\circ_{2\frac{1}{2}}$ | 105668.78 | 105676 | −7 |
| $3d^8(^3F_3)5p$ | $5p$ | $^2F^\circ_{3\frac{1}{2}}$ | 105838.06 | 105873 | −35 |
| $3d^8(^3F_3)5p$ | $5p$ | $^2D^\circ_{2\frac{1}{2}}$ | 105861.19 | 105872 | −11 |
| $3d^7(^4P)sp(^3P)$ | $y$ | $^6D^\circ_{5\frac{1}{2}}$ | 105981.50? | 105931 | +50 |
| $3d^8(^3F_2)5p$ | $5p$ | $^4D^\circ_{0\frac{1}{2}}$ | 106022.79 | 106042 | −19 |
| $3d^8(^3F_2)5p$ | $5p$ | $^4G^\circ_{2\frac{1}{2}}$ | 106283.16 | 106229 | +54 |
| $3d^8(^3F_2)5p$ | $5p$ | $^4F^\circ_{1\frac{1}{2}}$ | 106369.30 | 106410 | −41 |
| $3d^8(^3F_2)5p$ | $5p$ | $^2G^\circ_{3\frac{1}{2}}$ | 106620.53 | 106643 | −22 |
| $3d^8(^3F_2)5p$ | $5p$ | $^2F^\circ_{2\frac{1}{2}}$ | 107082.21 | 107107 | −25 |
| $3d^8(^3F_2)5p$ | $5p$ | $^2D^\circ_{1\frac{1}{2}}$ | 107142.21 | 107138 | +4 |
| $3d^7(^4P)sp(^3P)$ | $z$ | $^4S^\circ_{1\frac{1}{2}}$ | 107737.81 | 107810 | −72 |
| $3d^7(^4P)sp(^3P)$ | $z$ | $^6P^\circ_{1\frac{1}{2}}$ | 109038.84 | 109005 | +34 |
| $3d^7(^2G)sp(^3P)$ | $y$ | $^4F^\circ_{4\frac{1}{2}}$ | 109148.05 | 109102 | +46 |
| $3d^7(^2G)sp(^3P)$ | $y$ | $^4F^\circ_{3\frac{1}{2}}$ | 109846.00 | 109818 | +28 |
| $3d^7(^2G)sp(^3P)$ | $y$ | $^4G^\circ_{4\frac{1}{2}}$? | 110021.92 | 111703 | −1681 |
| $3d^7(^2G)sp(^3P)$ | $y$ | $^4F^\circ_{2\frac{1}{2}}$ | 110573.36 | 110460 | +113 |
| $3d^7(^2G)sp(^3P)$ | $y$ | $^4F^\circ_{1\frac{1}{2}}$ | 111120.54 | 110944 | +177 |
| $3d^7(^2G)sp(^3P)$ | $y$ | $^4G^\circ_{3\frac{1}{2}}$ | 111783.79 | 111951 | −167 |
| $3d^7(^4F)sp(^1P)$ | $x$ | $^4G^\circ_{5\frac{1}{2}}$ | 112422.19? | 112818 | −396 |
| $3d^7(^4F)sp(^1P)$ | $x$ | $^4F^\circ_{4\frac{1}{2}}$ | 113321.95 | 113064 | +258 |
| $3d^7(^4F)sp(^1P)$ | $x$ | $^4G^\circ_{4\frac{1}{2}}$ | 113753.04 | 113893 | −140 |
| $3s^7(^4F)sp(^1P)$ | $x$ | $^4F^\circ_{3\frac{1}{2}}$ | 114052.04 | 113841 | +211 |
| $3d^7(^2H)sp(^3P)$ | $w$ | $^4G^\circ_{5\frac{1}{2}}$ | 114858.88 | 114822 | +37 |
| $3d^7(^2P)sp(^3P)$ | $w$ | $^4D^\circ_{1\frac{1}{2}}$ | 114869.35 | 115058 | −189 |
| $3d^7(^2P)sp(^3P)$ | $w$ | $^4D^\circ_{3\frac{1}{2}}$ | 115000.25 | 115277 | −277 |
| $3d^7(^2P)sp(^3P)$ | $w$ | $^4D^\circ_{2\frac{1}{2}}$ | 115108.09 | 115301 | −193 |
| $3d^7(^4F)sp(^1P)$ | $x$ | $^4F^\circ_{2\frac{1}{2}}$ | 115120.00? | 114897 | +223 |
| $3d^7(^4F)sp(^1P)$ | $x$ | $^4G^\circ_{3\frac{1}{2}}$ | 115209.85 | 114832 | +378 |
| $3d^7(^4F)sp(^1P)$ | $x$ | $^4G^\circ_{2\frac{1}{2}}$ | 115565.98 | 115499 | +67 |
| $3d^7(^4F)sp(^1P)$ | $x$ | $^4F^\circ_{1\frac{1}{2}}$ | 115592.25? | 115274 | +318 |
| $3d^7(^2P)sp(^3P)$ | $t$ | $^2D^\circ_{1\frac{1}{2}}$ | 115785.06 | 115707 | +78 |
| $3d^7(^2H)sp(^3P)$ | $w$ | $^4G^\circ_{4\frac{1}{2}}$ | 116087.38 | 115529 | +558 |
| $3d^7(^2H)sp(^3P)$ | $w$ | $^4G^\circ_{3\frac{1}{2}}$ | 116275.81 | 116170 | +106 |
| $3d^7(^2D)sp(^3P)$ | $v$ | $^4D^\circ_{3\frac{1}{2}}$ | 116512.06 | 116903 | −391 |
| $3d^7(^2H)sp(^3P)$ | $w$ | $^4G^\circ_{2\frac{1}{2}}$ | 116824.15 | 116614 | +210 |
| $3d^7(^2D)sp(^3P)$ | $v$ | $^4D^\circ_{2\frac{1}{2}}$ | 116893.98 | 117125 | −231 |
| $3d^7(^2D)sp(^3P)$ | $w$ | $^4F^\circ_{4\frac{1}{2}}$ | 117573.68 | 118039 | −465 |
| $3d^7(^2D)sp(^3P)$ | $v$ | $^4D^\circ_{1\frac{1}{2}}$ | 117662.11 | 118000 | −338 |
| $3d^8(^1D)5p$ | $5p'$ | $^2D^\circ_{1\frac{1}{2}}$ | 117763.91 | 117798 | −34 |
| $3d^8(^1D)5p$ | $5p'$ | $^2D^\circ_{2\frac{1}{2}}$ | 117872.78 | 117894 | −21 |
| $3d^7(^2D)sp(^3P)$ | $w$ | $^4F^\circ_{3\frac{1}{2}}$ | 117972.47 | 118369 | −397 |
| $3d^7(^2H)sp(^3P)$ | $z$ | $^2I^\circ_{5\frac{1}{2}}$ | 118248.98 | 118195 | +54 |
| $3d^8(^1D)5p$ | $5p'$ | $^2F^\circ_{2\frac{1}{2}}$ | 118379.11 | 118484 | −105 |
| $3d^8(^1D)5p$ | $5p'$ | $^2P^\circ_{1\frac{1}{2}}$ | 118442.81 | 118397 | +46 |
| $3d^8(^1D)5p$ | $5p'$ | $^2F^\circ_{3\frac{1}{2}}$ | 118563.39 | 118617 | −54 |
| $3d^8(^1D)5p$ | $5p'$ | $^2P^\circ_{0\frac{1}{2}}$ | 118631.95 | 118575 | +57 |
| $3d^8(^3F_4)4f$ | $4f$ | $^2S^\circ_{0\frac{1}{2}}$ | 118774.76 | 118805 | −30 |
| $3d^8(^3F_4)4f$ | $4f$ | $^4I^\circ_{6\frac{1}{2}}$ | 118803.82 | 118840 | −36 |
| $3d^8(^3F_4)4f$ | $4f$ | $^4S^\circ_{1\frac{1}{2}}$ | 118809.34? | 118801 | +8 |
| $3d^8(^3F_4)4f$ | $4f$ | $^4P^\circ_{2\frac{1}{2}}$ | 118828.61 | 118834 | −5 |
| $3d^8(^3F_4)4f$ | $4f$ | $^4I^\circ_{7\frac{1}{2}}$ | 118848.92 | 118840 | +9 |
| $3d^8(^3F_4)4f$ | $4f$ | $^4D^\circ_{3\frac{1}{2}}$ | 118874.11 | 118873 | +1 |
| $3d^8(^3F_4)4f$ | $4f$ | $^4P^\circ_{1\frac{1}{2}}$ | 118877.09 | 118849 | +28 |
| $3d^8(^3F_4)4f$ | $4f$ | $^4H^\circ_{5\frac{1}{2}}$ | 118892.99 | 118912 | −19 |
| $3d^8(^3F_4)4f$ | $4f$ | $^4H^\circ_{6\frac{1}{2}}$ | 118893.24 | 118912 | −19 |
| $3d^8(^3F_4)4f$ | $4f$ | $^4D^\circ_{2\frac{1}{2}}$ | 118897.94 | 118895 | +3 |
| $3d^8(^3F_4)4f$ | $4f$ | $^4G^\circ_{4\frac{1}{2}}$ | 118914.34 | 118908 | +6 |
| $3d^8(^3F_4)4f$ | $4f$ | $^4F^\circ_{3\frac{1}{2}}$ | 118923.20 | 118923 | 0 |
| $3d^8(^3F_4)4f$ | $4f$ | $^4F^\circ_{4\frac{1}{2}}$ | 118927.02 | 118928 | −1 |
| $3d^8(^3F_4)4f$ | $4f$ | $^4G^\circ_{3\frac{1}{2}}$ | 118939.53 | 118928 | +12 |
| $3d^7(^2H)sp(^3P)$ | $z$ | $^2I^\circ_{6\frac{1}{2}}$ | 119010.21 | 118817 | +193 |
| $3d^8(^3P)5p$ | $5p''$ | $^4P^\circ_{2\frac{1}{2}}$ | 119796.98 | 119814 | −17 |

TABLE III. Ni II *Odd levels (1970)*—Continued

| Configuration | Name | Level Observed | Level Computed | O–C |
|---|---|---|---|---|
| $3d^8(^3P)5p$ | $5p''\ ^4P^\circ_{1\frac{1}{2}}$ | 120166.52 | 119822 | +345 |
| $3d^8(^3F_3)4f$ | $4f\ ^2P^\circ_{0\frac{1}{2}}$ | 120189.55 | 120169 | +21 |
| $3d^8(^3F_3)4f$ | $4f\ ^2P^\circ_{1\frac{1}{2}}$ | 120199.18 | 120192 | +7 |
| $3d^8(^3F_3)4f$ | $4f\ ^4F^\circ_{2\frac{1}{2}}$ | 120203.49 | 120182 | +21 |
| $3d^8(^3F_3)4f$ | $4f\ ^4I^\circ_{5\frac{1}{2}}$ | 120211.30 | 120207 | +4 |
| $3d^8(^3F_3)4f$ | $4f\ ^2I^\circ_{6\frac{1}{2}}$ | 120218.22 | 120207 | +11 |
| $3d^8(^3F_3)4f$ | $4f\ ^4D^\circ_{1\frac{1}{2}}$ | 120222.89 | 120223 | 0 |
| $3d^8(^3F_3)4f$ | $4f\ ^4G^\circ_{3\frac{1}{2}}$ | 120250.17 | 120251 | −1 |
| $3d^8(^3F_3)4f$ | $4f\ ^2F^\circ_{3\frac{1}{2}}$ | 120268.81 | 120281 | −12 |
| $3d^8(^3F_3)4f$ | $4f\ ^2H^\circ_{5\frac{1}{2}}$ | 120270.44 | 120268 | +2 |
| $3d^8(^3F_3)4f$ | $4f\ ^2D^\circ_{2\frac{1}{2}}$ | 120271.97 | 120263 | +9 |
| $3d^8(^3F_3)4f$ | $4f\ ^4H^\circ_{4\frac{1}{2}}$ | 120272.53 | 120268 | +5 |
| $3d^8(^3F_3)4f$ | $4f\ ^2G^\circ_{4\frac{1}{2}}$ | 120281.11 | 120274 | +7 |
| $3d^8(^3P)5p$ | $5p''\ ^4P^\circ_{0\frac{1}{2}}$ | 120316.02 | 120174 | +142 |
| $3d^8(^3P)5p$ | $5p''\ ^4D^\circ_{3\frac{1}{2}}$ | 120903.20 | 121027 | −124 |
| $3d^8(^3F_2)4f$ | $4f\ ^2D^\circ_{1\frac{1}{2}}$ | 121042.52 | 121090 | −48 |
| $3d^8(^3P)5p$ | $5p''\ ^2P^\circ_{1\frac{1}{2}}$ | 121042.57 | 121007 | +36 |
| $3d^8(^3P)5p$ | $5p''\ ^4D^\circ_{2\frac{1}{2}}$ | 121050.66 | 121318 | −267 |
| $3d^8(^3F_2)4f$ | $4f\ ^4D^\circ_{0\frac{1}{2}}$ | 121090.71 | 121090 | +1 |
| $3d^8(^3F_2)4f$ | $4f\ ^2I^\circ_{5\frac{1}{2}}$ | 121120.88 | 121124 | −3 |
| $3d^8(^3F_2)4f$ | $4f\ ^4I^\circ_{4\frac{1}{2}}$ | 121125.41 | 121124 | +1 |
| $3d^8(^3F_2)4f$ | $4f\ ^4G^\circ_{2\frac{1}{2}}$ | 121146.98 | 121144 | +3 |
| $3d^8(^3F_2)4f$ | $4f\ ^4F^\circ_{1\frac{1}{2}}$ | 121161.81 | 121145 | +17 |
| $3d^8(^3F_2)4f$ | $4f\ ^2G^\circ_{3\frac{1}{2}}$ | 121178.56 | 121193 | −14 |
| $3d^8(^3F_2)4f$ | $4f\ ^2H^\circ_{4\frac{1}{2}}$ | 121180.54 | 121192 | −11 |
| $3d^8(^3F_2)4f$ | $4f\ ^4H^\circ_{3\frac{1}{2}}$ | 121192.32 | 121184 | +8 |
| $3d^8(^3F_2)4f$ | $4f\ ^2F^\circ_{2\frac{1}{2}}$ | 121194.14 | 121187 | +7 |
| $3d^8(^3P)5p$ | $5p''\ ^2D^\circ_{2\frac{1}{2}}$ | 121325.09 | 121079 | +246 |
| $3d^8(^3P)5p$ | $5p''\ ^4D^\circ_{1\frac{1}{2}}$ | 121385.80 | 121338 | +48 |
| $3d^8(^3P)5p$ | $5p''\ ^4S^\circ_{1\frac{1}{2}}$ | 121456.32 | 121424 | +32 |
| $3d^8(^3P)5p$ | $5p''\ ^4D^\circ_{0\frac{1}{2}}$ | 121561.06 | 121506 | +55 |
| $3d^7(^2H)sp(^3P)$ | $x\ ^2G^\circ_{4\frac{1}{2}}$ | 121692.55 | 121483 | +210 |
| $3d^8(^3P)5p$ | $5p''\ ^2D^\circ_{1\frac{1}{2}}$ | 121800.34 | 121649 | +151 |
| $3d^7(^2H)sp(^3P)$ | $x\ ^2G^\circ_{3\frac{1}{2}}$ | 121862.57 | 121608 | +255 |
| $3d^8(^3F_4)6p$ | $6p\ ^4G^\circ_{5\frac{1}{2}}$ | 121120.37 | | |
| $3d^8(^3F_4)6p$ | $6p\ ^4F^\circ_{4\frac{1}{2}}$? | 122441.22 | | |
| $3d^8(^3F_4)6p$ | $6p\ ^4D^\circ_{3\frac{1}{2}}$ | 122812.97 | | |
| $3d^8(^3F_3)6p$ | $6p\ ^2G^\circ_{4\frac{1}{2}}$ | 123434.60 | | |
| $3d^7(^2H)sp(^3P)$ | $y\ ^2H^\circ_{4\frac{1}{2}}$ | 124652.00 | 124681 | −29 |
| $3d^7(^2H)sp(^3P)$ | $y\ ^2H^\circ_{5\frac{1}{2}}$ | 125003.44 | 125025 | −22 |
| $3d^8(^1G)5p$ | $5p'''\ ^2H^\circ_{4\frac{1}{2}}$ | 126679.98 | 126979 | −299 |
| $3d^7(^4P)sp(^1P)$ | $x\ ^4S^\circ_{1\frac{1}{2}}$? | 126738.82 | 127058 | −319 |
| $3d^8(^1G)5p$ | $5p'''\ ^2H^\circ_{5\frac{1}{2}}$ | 126857.97 | 127106 | −248 |
| $3d^8(^1G)5p$ | $5p'''\ ^2F^\circ_{3\frac{1}{2}}$ | 127219.97 | 126712 | +508 |
| $3d^8(^1G)5p$ | $5p'''\ ^2F^\circ_{2\frac{1}{2}}$ | 127331.60 | 126801 | +531 |
| $3d^8(^1G)5p$ | $5p'''\ ^2G^\circ_{4\frac{1}{2}}$ | 127885.86 | 127962 | −76 |
| $3d^8(^1G)5p$ | $5p'''\ ^2G^\circ_{3\frac{1}{2}}$ | 127895.33 | 127964 | −69 |
| $3d^8(^3F_4)5f$ | $5f\ ^4S^\circ_{1\frac{1}{2}}$ | 128732.03 | | |
| $3d^8(^3F_4)5f$ | $5f\ ^2S^\circ_{0\frac{1}{2}}$ | 128799.72 | | |
| $3d^8(^3F_4)5f$ | $5f\ ^4P^\circ_{2\frac{1}{2}}$ | 128803.23 | | |
| $3d^8(^3F_4)5f$ | $5f\ ^4I^\circ_{6\frac{1}{2}}$ | 128818.41 | | |
| $3d^8(^3F_4)5f$ | $5f\ ^4P^\circ_{1\frac{1}{2}}$ | 128822.23 | | |
| $3d^8(^3F_4)5f$ | $5f\ ^4I^\circ_{7\frac{1}{2}}$ | 128827.05 | | |
| $3d^8(^3F_4)5f$ | $5f\ ^4D^\circ_{3\frac{1}{2}}$ | 128827.15 | | |
| $3d^8(^3F_4)5f$ | $5f\ ^4H^\circ_{5\frac{1}{2}}$ | 128837.11 | | |
| $3d^8(^3F_4)5f$ | $5f\ ^4D^\circ_{2\frac{1}{2}}$ | 128853.87 | | |
| $3d^8(^3F_4)5f$ | $5f\ ^4G^\circ_{4\frac{1}{2}}$ | 128853.91 | | |
| $3d^8(^3F_4)5f$ | $5f\ ^4H^\circ_{6\frac{1}{2}}$ | 128855.60 | | |
| $3d^8(^3F_4)5f$ | $5f\ ^4F^\circ_{4\frac{1}{2}}$ | 128862.49 | | |
| $3d^8(^3F_4)5f$ | $5f\ ^4F^\circ_{2\frac{1}{2}}$ | 128867.00 | | |
| $3d^8(^3F_4)5f$ | $5f\ ^4G^\circ_{5\frac{1}{2}}$ | 128869.89 | | |
| $3d^7(^4P)sp(^1P)$ | $t\ ^4D^\circ_{3\frac{1}{2}}$ | 129782.07 | 130301 | −519 |
| $3d^7(^4P)sp(^1P)$ | $t\ ^4D^\circ_{2\frac{1}{2}}$ | 129988.05 | 130483 | −495 |
| $3d^8(^3F_3)5f$ | $5f\ ^4P^\circ_{0\frac{1}{2}}$ | 130147.87 | | |
| $3d^8(^3F_3)5f$ | $5f\ ^2P^\circ_{1\frac{1}{2}}$ | 130174.03 | | |
| $3d^8(^3F_3)5f$ | $5f\ ^4F^\circ_{2\frac{1}{2}}$ | 130184.39 | | |
| $3d^8(^3F_3)5f$ | $5f\ ^4I^\circ_{5\frac{1}{2}}$ | 130184.61 | | |
| $3d^8(^3F_3)5f$ | $5f\ ^2I^\circ_{6\frac{1}{2}}$ | 130187.81 | | |
| $3d^8(^3F_3)5f$ | $5f\ ^4D^\circ_{1\frac{1}{2}}$ | 130197.23 | | |
| $3d^8(^3F_3)5f$ | $5f\ ^2H^\circ_{5\frac{1}{2}}$ | 130205.62 | | |
| $3d^8(^3F_3)5f$ | $5f\ ^4H^\circ_{4\frac{1}{2}}$ | 130206.90 | | |
| $3d^8(^3F_3)5f$ | $5f\ ^4G^\circ_{3\frac{1}{2}}$ | 130208.89 | | |

TABLE III. Ni II *Odd levels (1970)*—Continued

| Configuration | Name | | Level Observed | Level Computed | O–C |
|---|---|---|---|---|---|
| $3d^8(^3F_3)5f$ | $5f$ | $^2G^\circ_{4\frac{1}{2}}$ | 130215.50 | | |
| $3d^8(^3F_3)5f$ | $5f$ | $^2F^\circ_{3\frac{1}{2}}$ | 130225.87 | | |
| $3d^8(^3F_3)5f$ | $5f$ | $^2D^\circ_{2\frac{1}{2}}$ | 130227.52 | | |
| $3d^7(^4P)sp(^1P)$ | $t$ | $^4D^\circ_{1\frac{1}{2}}$ | 130331.78 | 130732 | −400 |
| $3d^8(^3F_4)7p$ | $7p$ | $^4F^\circ_{4\frac{1}{2}}$? | 130470.90 | | |
| $3d^8(^3F_4)7p$ | $7p$ | $^4D^\circ_{3\frac{1}{2}}$ | 130480.55 | | |
| $3d^7(^4P)sp(^1P)$ | $t$ | $^4D^\circ_{0\frac{1}{2}}$ | 130570.42 | 130953 | −383 |
| $3d^8(^3F_4)7p$ | $7p$ | $^4G^\circ_{5\frac{1}{2}}$ | 130661.32 | | |
| $3d^8(^3F_2)5f$ | $5f$ | $^4D^\circ_{0\frac{1}{2}}$ | 131063.85 | | |
| $3d^8(^3F_2)5f$ | $5f$ | $^2D^\circ_{1\frac{1}{2}}$ | 131075.78 | | |
| $3d^8(^3F_2)5f$ | $5f$ | $^2H^\circ_{4\frac{1}{2}}$ | 131093.30 | | |
| $3d^8(^3F_2)5f$ | $5f$ | $^4G^\circ_{2\frac{1}{2}}$ | 131103.18 | | |
| $3d^8(^3F_2)5f$ | $5f$ | $^4I^\circ_{4\frac{1}{2}}$ | 131115.28 | | |
| $3d^8(^3F_2)5f$ | $5f$ | $^2I^\circ_{5\frac{1}{2}}$ | 131122.28? | | |
| $3d^8(^3F_2)5f$ | $5f$ | $^2G^\circ_{3\frac{1}{2}}$ | 131124.96 | | |
| $3d^8(^3F_2)5f$ | $5f$ | $^2F^\circ_{2\frac{1}{2}}$ | 131133.58 | | |
| $3d^7(^2G)sp(^1P)$ | $x$ | $^2H^\circ_{5\frac{1}{2}}$ | 131424.32? | 131225 | +199 |
| $3d^7(^4P)sp(^1P)$ | $v$ | $^4P^\circ_{2\frac{1}{2}}$ | 131834.94 | 133393 | −1558 |
| $3d^8(^3F_3)7p$ | $7p$ | $^2G^\circ_{4\frac{1}{2}}$ | 131928.77 | | |
| $3d^7(^4P)sp(^1P)$ | $v$ | $^4P^\circ_{0\frac{1}{2}}$ | 132120.70 | 133715 | −1594 |
| $3d^7(^4P)sp(^1P)$ | $v$ | $^4P^\circ_{1\frac{1}{2}}$ | 132225.15 | 133715 | −1490 |
| $3d^7(^2G)sp(^1P)$ | $x$ | $^2H^\circ_{4\frac{1}{2}}$ | 132311.98? | 132201 | +111 |
| $3d^8(^1D)4f$ | $4f'$ | $^2F^\circ_{2\frac{1}{2}}$ | 132729.48 | 132875 | −146 |
| $3d^8(^1D)4f$ | $4f'$ | $^2G^\circ_{4\frac{1}{2}}$ | 132818.16 | 132856 | −38 |
| $3d^8(^1D)4f$ | $4f'$ | $^2G^\circ_{3\frac{1}{2}}$ | 132846.53 | 132857 | −10 |
| $3d^8(^1D)4f$ | $4f'$ | $^2F^\circ_{3\frac{1}{2}}$ | 132869.16 | 132885 | −16 |
| $3d^8(^1D)4f$ | $4f'$ | $^2D^\circ_{2\frac{1}{2}}$ | 132912.15 | 132943 | −31 |
| $3d^8(^1D)4f$ | $4f'$ | $^2D^\circ_{1\frac{1}{2}}$ | 132927.97 | 132940 | −12 |
| $3d^8(^1D)4f$ | $4f'$ | $^2P^\circ_{1\frac{1}{2}}$ | 132982.51 | 133007 | −24 |
| $3d^8(^1D)4f$ | $4f'$ | $^2P^\circ_{0\frac{1}{2}}$ | 133001.47 | 133007 | −6 |
| $3d^8(^1D)4f$ | $4f'$ | $^2H^\circ_{5\frac{1}{2}}$ | 133014.08 | 132952 | +62 |
| $3d^8(^1D)4f$ | $4f'$ | $^2H^\circ_{4\frac{1}{2}}$ | 133031.00 | 132952 | +79 |
| $3d^7(^2G)sp(^1P)$ | $w$ | $^2F^\circ_{3\frac{1}{2}}$ | 133169.92 | 132985 | +185 |
| $3d^7(^2F)sp(^3P)$ | $v$ | $^4F^\circ_{1\frac{1}{2}}$ | 133190.19? | 133016 | +174 |
| $3d^7(^2F)sp(^3P)$ | $v$ | $^4F^\circ_{2\frac{1}{2}}$ | 133209.30 | 133251 | −42 |
| $3d^7(^2G)sp(^1P)$ | $w$ | $^2G^\circ_{4\frac{1}{2}}$ | 133445.75 | 133724 | −278 |
| $3d^7(^2F)sp(^3P)$ | $v$ | $^4F^\circ_{3\frac{1}{2}}$ | 133528.02 | 133578 | −50 |
| $3d^7(^2F)sp(^3P)$ | $v$ | $^4G^\circ_{5\frac{1}{2}}$ | 133625.96 | 133461 | +165 |
| $3d^7(^2F)sp(^3P)$ | $s$ | $^4D^\circ_{3\frac{1}{2}}$ | 133850.83 | 133917 | −66 |
| $2d^7(^2F)sp(^3P)$ | $v$ | $^4F^\circ_{4\frac{1}{2}}$ | 133853.04 | 133906 | −53 |
| $3d^7(^2F)sp(^3P)$ | $s$ | $^4D^\circ_{2\frac{1}{2}}$ | 133973.33 | 133904 | +69 |
| $3d^7(^2F)sp(^3P)$ | $s$ | $^4D^\circ_{1\frac{1}{2}}$ | 134156.28 | 134112 | +44 |
| $3d^7(^2G)sp(^1P)$ | $w$ | $^2F^\circ_{2\frac{1}{2}}$ | 134208.30 | 134160 | +48 |
| $3d^8(^3F_4)6f$ | $6f$ | $^4I^\circ_{6\frac{1}{2}}$ | 134238.44 | | |
| $3d^8(^3F_4)6f$ | $6f$ | $^4P^\circ_{1\frac{1}{2}}$ | 134249.72 | | |
| $3d^8(^3F_4)6f$ | $6f$ | $^4I^\circ_{7\frac{1}{2}}$ | 134251.30 | | |
| $3d^8(^3F_4)6f$ | $6f$ | $^4F^\circ_{3\frac{1}{2}}$ | 134252.85 | | |
| $3d^8(^3F_4)6f$ | $6f$ | $^4S^\circ_{1\frac{1}{2}}$ | 134254.69 | | |
| $3d^8(^3F_4)6f$ | $6f$ | $^4P^\circ_{2\frac{1}{2}}$ | 134256.05 | | |
| $3d^8(^3F_4)6f$ | $6f$ | $^4D^\circ_{3\frac{1}{2}}$ | 134262.07 | | |
| $3d^8(^3F_4)6f$ | $6f$ | $^4H^\circ_{6\frac{1}{2}}$ | 134267.20 | | |
| $3d^8(^3F_4)6f$ | $6f$ | $^4F^\circ_{4\frac{1}{2}}$ | 134271.59 | | |
| $3d^8(^3F_4)6f$ | $6f$ | $^4G^\circ_{5\frac{1}{2}}$ | 134274.62 | | |
| $3d^8(^3F_4)6f$ | $6f$ | $^4H^\circ_{5\frac{1}{2}}$ | 134281.66 | | |
| $3d^7(^2F)sp(^3P)$ | $s$ | $^4D^\circ_{0\frac{1}{2}}$ | 134283.76 | 134193 | +91 |
| $3d^8(^3F_4)6f$ | $6f$ | $^4G^\circ_{4\frac{1}{2}}$ | 134286.38 | | |
| $3d^8(^3F_4)6f$ | $6f$ | $^4D^\circ_{2\frac{1}{2}}$ | 134294.99 | | |
| $3d^7(^2G)sp(^1P)$ | $w$ | $^2G^\circ_{3\frac{1}{2}}$ | 134380.82 | 134827 | −446 |
| $3d^7(^2F)sp(^3P)$ | $w$ | $^2D^\circ_{2\frac{1}{2}}$ | 134783.14 | 134956 | −173 |
| $3d^7(^2F)sp(^3P)$ | $w$ | $^2D^\circ_{1\frac{1}{2}}$? | 134964.78 | 134155 | −190 |
| $3d^7(^2P)sp(^1P)$ | $v$ | $^2D^\circ_{2\frac{1}{2}}$ | 135258.92 | 136090 | −831 |
| $3d^8(^3F_4)8p$ | $8p$ | $^4G^\circ_{4\frac{1}{2}}$ | 135261.99 | | |
| $3d^8(^3F_4)8p$ | $8p$ | $^4G^\circ_{5\frac{1}{2}}$ | 135338.01 | | |
| $3d^7(^2P)sp(^1P)$ | $w$ | $^2P^\circ_{1\frac{1}{2}}$ | 135382.53 | 135737 | −354 |
| $3d^8(^3P)4f$ | $4f''$ | $^2F^\circ_{3\frac{1}{2}}$ | 135400.67 | 135436 | −35 |
| $3d^8(^3P)4f$ | $4f''$ | $^4F^\circ_{4\frac{1}{2}}$ | 135435.26 | 135413 | +22 |
| $3d^8(^3P)4f$ | $4f''$ | $^4F^\circ_{3\frac{1}{2}}$ | 135444.47 | 135425 | +19 |
| $3d^8(^3P)4f$ | $4f''$ | $^4F^\circ_{2\frac{1}{2}}$ | 135461.55 | 135477 | +15 |
| $3d^8(^3P)4f$ | $4f''$ | $^2G^\circ_{3\frac{1}{2}}$ | 135464.86 | 135776 | −311 |
| $3d^8(^3P)4f$ | $4f''$ | $^4F^\circ_{1\frac{1}{2}}$ | 135493.26 | 135483 | +10 |
| $3d^8(^3P)4f$ | $4f''$ | $^2D^\circ_{2\frac{1}{2}}$ | 135512.92 | 135494 | +19 |
| $3d^8(^3P)4f$ | $4f''$ | $^4G^\circ_{5\frac{1}{2}}$ | 135538.61? | 135583 | −44 |

TABLE III. Ni II *Odd levels (1970)*—Continued

| Configuration | Name | Level Observed | Level Computed | O–C | Configuration | Name | Level Observed | Level Computed | O–C |
|---|---|---|---|---|---|---|---|---|---|
| $3d^8(^3P)4f$ | $4f''$ $^4G^\circ_{11/2}$ | 135558.80 | 135583 | −24 | $3d^8(^3F_2)6f$ | $6f$ $^2I^\circ_{5\frac{1}{2}}$ | 136508.20 | | |
| $3d^8(^3P)4f$ | $4f''$ $^2G^\circ_{11/2}$? | 135580.25 | 135773 | −193 | $3d^8(^3F_2)6f$ | $6f$ $^4D^\circ_{0\frac{1}{2}}$ | 136517.20 | | |
| $3d^8(^3F_3)6f$ | $6f$ $^2P^\circ_{0\frac{1}{2}}$ | 135599.00 | | | $3d^8(^3F_2)6f$ | $6f$ $^4I^\circ_{4\frac{1}{2}}$ | 136524.42 | | |
| $3d^8(^3F_3)6f$ | $6f$ $^4I^\circ_{5\frac{1}{2}}$ | 135606.20 | | | $3d^8(^3F_2)6f$ | $6f$ $^4F^\circ_{1\frac{1}{2}}$ | 136531.26 | | |
| $3d^8(^3F_3)6f$ | $6f$ $^2I^\circ_{6\frac{1}{2}}$ | 135606.30 | | | $3d^8(^3F_2)6f$ | $6f$ $^4H^\circ_{3\frac{1}{2}}$ | 136542.28 | | |
| $3d^8(^3F_3)6f$ | $6f$ $^4F^\circ_{2\frac{1}{2}}$ | 135618.08 | | | $3d^8(^3F_2)6f$ | $6f$ $^2H^\circ_{4\frac{1}{2}}$ | 136546.50 | | |
| $3d^8(^3F_3)6f$ | $6f$ $^4D^\circ_{1\frac{1}{2}}$ | 135619.91 | | | $3d^8(^3F_2)6f$ | $6f$ $^2G^\circ_{3\frac{1}{2}}$ | 136547.13 | | |
| $3d^8(^3F_3)6f$ | $6f$ $^4G^\circ_{3\frac{1}{2}}$ | 135622.60 | | | $3d^8(^3F_2)6f$ | $6f$ $^4G^\circ_{2\frac{1}{2}}$ | 136548.55 | | |
| $3d^8(^5F_3)6f$ | $6f$ $^2P^\circ_{1\frac{1}{2}}$ | 135623.59 | | | $3d^8(^3F_3)8p$ | $8p$ $^2G^\circ_{4\frac{1}{2}}$ | 136673.64 | | |
| $3d^8(^5F_3)6f$ | $6f$ $^2G^\circ_{4\frac{1}{2}}$ | 135628.41 | | | $3d^8(^3F_4)7f$ | $7f$ $^4P^\circ_{2\frac{1}{2}}$ | 137519.23 | | |
| $3d^8(^5F_3)6f$ | $6f$ $^2F^\circ_{3\frac{1}{2}}$ | 135629.40 | | | $3d^8(^3F_4)7f$ | $7f$ $^4I^\circ_{7\frac{1}{2}}$ | 137519.63 | | |
| $3d^8(^5F_3)6f$ | $6f$ $^2D^\circ_{2\frac{1}{2}}$ | 135630.63 | | | $3d^8(^3F_4)7f$ | $7f$ $^4D^\circ_{3\frac{1}{2}}$ | 137523.51? | | |
| $3d^8(^5F_3)6f$ | $6f$ $^4H^\circ_{1\frac{1}{2}}$ | 135640.53 | | | $3d^8(^3F_4)7f$ | $7f$ $^4D^\circ_{2\frac{1}{2}}$ | 137526.73 | | |
| $3d^8(^5F_3)6f$ | $6f$ $^2H^\circ_{5\frac{1}{2}}$ | 135645.10 | | | $3d^8(^3F_4)7f$ | $7f$ $^4H^\circ_{6\frac{1}{2}}$ | 137529.37 | | |
| $3d^8(^3P)4f$ | $4f''$ $^4D^\circ_{1\frac{1}{2}}$ | 135652.93 | 135663 | −10 | $3d^8(^3F_4)7f$ | $7f$ $^4F^\circ_{4\frac{1}{2}}$ | 137531.18 | | |
| $3d^8(^3P)4f$ | $4f''$ $^4D^\circ_{0\frac{1}{2}}$ | 135670.49 | 135661 | +9 | $3d^8(^3F_4)7f$ | $7f$ $^4G^\circ_{5\frac{1}{2}}$ | 137535.83 | | |
| $3d^7(^2F)sp(^3P)$ | $o$ $^2G^\circ_{3\frac{1}{2}}$ | 135746.06 | 135789 | −43 | $3d^8(^3F_4)7f$ | $7f$ $^4F^\circ_{3\frac{1}{2}}$ | 137535.96 | | |
| $3d^8(^3P)4f$ | $4f''$ $^2D^\circ_{1\frac{1}{2}}$ | 135746.13 | 135785 | −39 | $3d^8(^3F_2)8p$ | $8p$ $^2G^\circ_{3\frac{1}{2}}$? | 137562.74 | | |
| $3d^8(^3P)4f$ | $4f''$ $^4D^\circ_{2\frac{1}{2}}$ | 135849.41 | 135867 | −18 | $3d^8(^3F_4)9p$ | $9p$ $^4F^\circ_{4\frac{1}{2}}$ | 138121.88 | | |
| $3d^8(^3P)4f$ | $4f''$ $^4G^\circ_{3\frac{1}{2}}$ | 135879.41 | 135866 | +13 | $3d^7(^2F)sp(^1P)$ | $w$ $^2G^\circ_{4\frac{1}{2}}$ | 138495.84? | 138576 | −80 |
| $3d^8(^3P)4f$ | $4f''$ $^4D^\circ_{3\frac{1}{2}}$? | 135954.09 | 136055 | −101 | $3d^8(^3P)6p$ | $6p''$ $^4D^\circ_{3\frac{1}{2}}$ | 138841.00 | | |
| $3d^7(^2F)sp(^3P)$ | $v$ $^2G^\circ_{4\frac{1}{2}}$ | 136076.26 | 135927 | +149 | $3d^8(^3F_3)7f$ | $7f$ $^2I^\circ_{6\frac{1}{2}}$ | 138888.93? | | |
| $3d^8(^3P)4f$ | $4f''$ $^2F^\circ_{2\frac{1}{2}}$ | 136122.61 | 136055 | +68 | $3d^8\,^3F_4$ | | 146541.56 | | |
| $3d^8(^1D)6p$ | $6p'$ $^2F^\circ_{3\frac{1}{2}}$? | 136392.85 | | | | | | | |

The differences of $4s\,^4F$ yielded many high levels, amongst them two terms due to $(^2F)sp(^3P)$, later called $v\,^4F^\circ$ and $s\,^4D^\circ$, which were useful to Shadmi in his calculations. Help also came from C. H. Corliss, of the National Bureau of Standards, who made a computer search by using all of the lines measured on the Bureau plates and all of the low even levels. Unfortunately the necessary allowance for inaccuracy of the wave numbers was great enough to make computed levels based on pairs of lines unreasonably frequent. Levels based on three lines were real in less than 50 percent of the cases and even five line levels were not always real. After many of the levels had been found by means of the calculated positions, it was discovered that some of them were present in the computer lists but buried in sheets of pairs of lines.

From a comparison of the empirical levels with the computed levels it seemed that many real levels appeared to have no counterpart in the list of calculated terms unless large differences between them were permitted. In fact it became evident that in some cases a group of actual levels gave agreement with a computed term with a nearly constant difference of up to 1600 $cm^{-1}$. This allowed a broadening of the search, so that eventually $w\,^4G$, $w\,^4F$, $w\,^4D$, $x\,^4F$, $t\,^4D$, $v\,^4P$ were found by this method.

Some remarks as follows must be made about certain identifications:

1. In the $4p'''$ group the value of the former level $^2F^\circ_{2\frac{1}{2}}$ has been replaced by 76402.04 $cm^{-1}$.

2. In the $5p$ group the computer identifies my $^2G^\circ_{4\frac{1}{2}}$ level as $^4G^\circ_{4\frac{1}{2}}$ contrary to all the experimental evidence.

It also places $^4F^\circ_{4\frac{1}{2}}$ as the lowest of the three levels and I have adopted that change.

3. All the levels of $5p'$ have been found, but the $^2F^\circ$ levels have much quartet nature. In the $5p''$ group the levels which combine like $^4D^\circ_{2\frac{1}{2}}$ and $^2D^\circ_{2\frac{1}{2}}$ fit very much better if the computed values are interchanged.

4. In the two terms $w\,^4D^\circ$ and $v\,^4D^\circ$ I have interchanged the computed values of $^4D^\circ_{3\frac{1}{2}}$ to improve the fit. Also the computed value of an unidentified level $t\,^2D^\circ_{1\frac{1}{2}}$ has been used for $v\,^4D^\circ_{2\frac{1}{2}}$ and $t\,^2D^\circ_{1\frac{1}{2}}$ has been used for $w\,^4D^\circ_{1\frac{1}{2}}$. The $w\,^4D^\circ_{1\frac{1}{2}}$ and $v\,^4D^\circ_{2\frac{1}{2}}$ calculated values are now placed as $t\,^2D^\circ_{1\frac{1}{2}}$ and $t\,^2D^\circ_{2\frac{1}{2}}$.

5. The doublet levels of $3d^7(^2H)sp(^3P)$, $z\,^2I^\circ$ and $y\,^2H^\circ$ are based on single very strong lines.

6. The term which deviates most from the calculated position is $v\,^4P^\circ$ with differences of $-1558$, $-1490$, $-1594$. All of these levels are well determined by combinations which show them to be typical $^4P^\circ$ levels.

As noted above, the $3d^8\,4f$ levels were calculated as an independent unit. The fit with the empirical levels is excellent in the group based on the $^3F$ limit, although lacking one level with $J=1/2$. The $4f'$ levels from $^1D$ also fit very well except the lowest and the two highest. Most of the levels are of mixed origin, judging from their combinations. The $4f''$ levels from $^3P$ proved much more difficult to identify chiefly because they are very mixed with $6f$ and $d^7\,sp$ levels. The levels $^2F^\circ_{3\frac{1}{2}}$, $^2G^\circ_{3\frac{1}{2}}$, $^4G^\circ_{3\frac{1}{2}}$, $^4D^\circ_{3\frac{1}{2}}$ are especially mixed. The $J$-values are definite but the names are rather arbitrary. One level of the group, 135,580, however, cannot be put in the same category as any of the other $4f''$ levels. It combines with $4d$ and $5d\,^4H_{4\frac{1}{2}}$, $^2G_{4\frac{1}{2}}$ and $^2G_{5\frac{1}{2}}$ and, therefore, has the character of $6f\,^2G_{4\frac{1}{2}}$ or $6f\,^2H_{5\frac{1}{2}}$. There is no place for it in the $6f$ group and it has been placed questionably as $4f''\,^2G_{4\frac{1}{2}}$.

## 5. Excitation in the Hollow Cathode

It is well established that excitation in the hollow cathode comes chiefly from collisions of the second kind with the excited or ionized atoms of the carrying gas and that the most probable excitation occurs when nearly the whole of the available energy is handed over.

The Ni II spectrum exhibits these effects more completely than any other spectrum with which I have worked. I have plotted the ratio of observed to predicted levels of $d^7\,sp$ from 94,000 to 136,000. The resulting curve has maxima of nearly 1.0 at each end and a minimum of 0.1 in the middle. The lack of uniform excitation in the tube can therefore take the blame for some of my failure to find many predicted terms in the intermediate range. It is also responsible for the difficulty of finding the $d^8\,6p$ levels since they fall in the central region. Some $7p$, $8p$ and $9p$ levels were more easily identified than the $6p$ ones, since they appear in the more efficient region.

## 6. Series Limits

There are many series from which to obtain the value of the limit $3d^8\,^3F_4$. The $3d^8\,ns$ series extends from $4s$ to $9s$ and the $3d^8\,nd$ series from $4d$ to $8d$. The $nf$ and $ng$ series are also available and they are usually preferred. Unfortunately there is a rather large discrepancy between the best component series of those groups.

The $ns\,^4F$ series appears to be unperturbed except that $7s\,^4F_{3\frac{1}{2}}$ is obviously low by about 20 cm$^{-1}$ to fit smoothly into the series, although there is apparently no perturbing term. By assuming that the $^4F_{4\frac{1}{2}}$ levels are unperturbed one finds by plotting that a limit of 146532.0 yields a nearly straight line corresponding to a Ritz formula. The same can be said of the series $nd\,^4H_{6\frac{1}{2}}$ and $nd\,^2H_{5\frac{1}{2}}$. The latter converges to $^3F_3$ which is 1360.7 cm$^{-1}$ above $^4F_{4\frac{1}{2}}$.

However, it is usually considered that the nearly hydrogenic series are more reliable. An exact fitting of $ng\,^4K_{8\frac{1}{2}}$ yields a limit of 146541.41 and $ng\,^4H_{6\frac{1}{2}}$ 146541.71. The difference of the average of those limits from that found from $ns$ and $nd$ series is 9.56 cm$^{-1}$ and the choice of either limit distorts the other series quite markedly.

There is no evidence to fix the choice unambiguously. The $ns\,^4F$ series may be perturbed by the levels of $3d^7\,4s\,5s$ which should be about 5000 cm$^{-1}$ above the $3d^8$ limit, but there is no obvious perturbing term for the $nd$ series. Although the $ng\,^4K_{8\frac{1}{2}}$ levels are all based on single strong lines, the $ng\,^4H_{6\frac{1}{2}}$ levels are determined quite certainly. Tentatively, therefore, I shall accept the limit based on the $ng$ series as being the more probably correct, i.e., 146541.56.

## 7. Unidentified Lines

The line list (table I) includes 4306 lines attributable to Ni II, of which 937 or 22 percent remain unclassified. Of the unclassified lines 159 are of intensity 15 or greater on the rather wide intensity scale I have used. It is possible that some of the lines in the Schuman region are due to the hydrogen molecule, but such lines would not be among the strong ones.

There are two regions which include most of the strong unclassified lines. The most important is from 69,000 cm$^{-1}$ to 65,000 cm$^{-1}$ where the even terms involved cannot be higher than $s^2\,^4P$ or just possibly $s^2\,^2G$. The only terms that are apt to give strong lines in this region are in fact $s^2\,^4F$ or $s^2\,^4P$. There are no unidentified calculated levels which should make strong combinations in that region with $s^2\,^4P$ and it must be concluded that $s^2\,^4F$ term is chiefly responsible for the unidentified lines. There are two predicted $^4D^\circ$ terms and a number of doublet terms in the proper energy range but a search for the intervals of the $s^2\,^4F$ term has yielded nothing that appears significant.

The other part of the spectrum where there are many unclassified lines is between 7000 and 9100 Å. The strong lines of this region are due mostly to transitions $5s-5p$ and $5p-6s$ which are all known, but there are a few unclassified lines of considerable intensity. It is possible that some of the weak lines are due to He bands which occur in some strength. However, over most of the region, the spectra were exposed in such a way that the band lines were distinguishable by their length.

Table IV is a synopsis of all the terms found in Ni II.

## TABLE IV. Ni II *Observed terms*

| Configuration | Observed Terms | | | | |
|---|---|---|---|---|---|
| $3d^9$ | $3d\ ^2D$ | | | | |
| $3d^7\,4s^2$ | $s^2\ ^4F\ ^4P\ ^2G\ ^2P\ ^2H\ ^2D\ ^2F$ | | | | |
| | $ns\ n \geq 4$ | $np\ n \geq 4$ | $nd\ n \geq 4$ | $nf\ n \geq 4$ | $ng\ n \geq 5$ |
| $3d^8(^3F)nx$ | $4s$ to $9s$ $^4F\ ^2F$ | $4p$ to $9p$ $^{4,2}D^\circ\ F^\circ\ G^\circ$ | $4d$ to $8d$ $^{4,2}P\ D\ F\ G\ H$ | $4f$ to $7f$ $^{4,2}S^\circ\ P^\circ\ D^\circ\ F^\circ\ G^\circ\ H^\circ\ I^\circ$ | $5g$ to $7g$ $^{4,2}P\ D\ F\ G\ H\ I\ K$ |
| $3d^8(^1D)nx$ | $4s'$ to $6s'$ $^2D$ | $4p'$ to $6p'$ $^2P^\circ\ D^\circ\ F^\circ$ | $4d'$, $5d'$ $^2S\ P\ D\ F\ G$ | $4f'$ $^2P^\circ\ D^\circ\ F^\circ\ G^\circ\ H^\circ$ | |
| $3d^8(^3P)nx$ | $4s''$ to $6s''$ $^4P\ ^2P$ | $4p''$ to $6p''$ $^{4,2}S^\circ\ P^\circ\ D^\circ$ | $4d''$, $5d''$ $^{4,2}P\ D\ F$ | $4f''$ $^{4,2}D^\circ\ F^\circ\ G^\circ$ | |
| $3d^8(^1G)nx$ | $4s'''$ to $6s'''$ $^2G$ | $4p'''$, $5p'''$ $^2F^\circ\ G^\circ H^\circ$ | $4d'''$ $^2F\ G\ H\ I$ | | |
| $3d^7(^4F)4s4p(^3P)$ | | $z^{6,4,2}D^\circ\ F^\circ\ G^\circ$ | | | |
| $(^4F)\quad(^1P)$ | | $x\ ^4F^\circ$, $x\ ^4G^\circ$ | | | |
| $(^4P)\quad(^3P)$ | | $z\ ^4S^\circ$, $y\ ^6D^\circ$? | | | |
| $(^4P)\quad(^1P)$ | | $x\ ^4S^\circ$, $v\ ^4P^\circ$, $t\ ^4D^\circ$ | | | |
| $(^2G)\quad(^3P)$ | | $y\ ^4F^\circ$, $y\ ^4G^\circ$ | | | |
| $(^2G)\quad(^1P)$ | | $w\ ^2F^\circ$, $w\ ^2G^\circ$, $x\ ^2H^\circ$ | | | |
| $(^2P)\quad(^3P)$ | | $w\ ^4D^\circ$, $t\ ^2D^\circ$, | | | |
| $(^2P)\quad(^1P)$ | | $w\ ^2P^\circ$, $v\ ^2D^\circ$ | | | |
| $(^2H)\quad(^3P)$ | | $w\ ^4G^\circ$, $x\ ^2G^\circ$, $y\ ^2H^\circ$, $z\ ^2I^\circ$ | | | |
| $(^2H)\quad(^1P)$ | | $u\ ^2G^\circ$? | | | |
| $(^2D)\quad(^3P)$ | | $v\ ^4D^\circ$, $w\ ^4F^\circ$ | | | |
| $(^2F)\quad(^3P)$ | | $s\ ^4D^\circ$, $v\ ^4F^\circ$, $v\ ^4G^\circ$, $w\ ^2D^\circ$, $v\ ^2G^\circ$ | | | |

This paper is the result of work which has occupied my attention for the past 5 years. Up to the spring of 1969, I was partially supported by a grant from the National Science Foundation and I also got much assistance from the Spectroscopy Section of the National Bureau of Standards. Especially, I would like to mention again the spectra taken by V. Kaufman on the Bureau's 10.6 meter vacuum instrument and measured by C. H. Corliss. Since April 1969 I have had the advantage of a part-time salary from a NASA contract held by L. C. Green of Haverford College. All of this assistance has made it possible for me to continue my full time research after my retirement from the faculty in physics at Princeton University. I have mentioned above the essential assistance given me by Y. Shadmi and by N. Spector. My colleagues and the University have been most cooperative in helping me with supplies, typing, etc., and especially ample space in which to work.

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[8] There are eight $^4D^\circ$ terms but in error the prefix *u* was omitted.

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# Publications of the National Bureau of Standards*

## Selected Abstracts

American National Standard, **Radiological safety in the design and operation of particle accelerators,** *Nat. Bur. Stand. (U.S.), Handb. 107, 22 pages (June 1970), 30 cents, SD Catalog No. C13.11:107.*

Key words: Accelerator design; accelerator operation; health physics; particle accelerators; radiation measurements; radiation protection; standard.

This American National Standard provides the basic considerations essential to the safe operation of a particle accelerator. It applied principally to particle accelerators with primary energies less than 100 MeV. It considers the characteristics of and controls for radiations as they affect accelerator design, operating procedures, and exposure evaluation. The section on radiation protection design criteria includes radiation shielding considerations and the use of safety systems. Operational health physics requirements are treated extensively, and radiation measurements are discussed in terms of the types of radiation that may be produced and proper techniques for monitoring. The final section, on dose assessment, includes basic exposure considerations such as maximum permissible dose and dose equivalent.

Arenhovel, H., Danos, M., Williams, H. T., **Baryon resonances in nuclei: magnetic moments of the deuteron,** *Physics Letters* **31B,** *No. 3, 109–112 (February 2, 1970).*

Key words: Baryon resonances; deuteron; exchange currents; magnetic moments; nuclear structure; photodisintegration.

Baryon resonance admixtures to the $p-n$ system have been calculated, as well as their effect on the static and transition magnetic moments of the deuteron.

Ballard, D. B., Yakowitz, H., **Investigation of secondary cracks from the failed Point Pleasant, West Virginia Bridge,** *Proc. Third Annual Scanning Electron Microscope Symp., April 1970, pp. 321–328 (Illinois Institute of Technology, Research Institute, Chicago, Ill., 1970).*

Key words: Electron probe microanalysis; ion microanalysis; metallography; non-dispersive x-ray analysis; Point Pleasant, W. Va. Bridge; scanning electron microscopy.

Secondary cracks in an eyebar of the Point Pleasant, W. Va. Bridge were investigated by means of scanning electron microscopy, electron probe microanalysis and optical metallographic techniques. The observed microstructure, surface topography, and sulfur gradient in the secondary cracks suggest the mechanism of stress corrosion as the cause for crack propagation.

Bennett, L. H., Swartzendruber, L. J., **On the interpretation of Mössbauer effect spectra as related to the constitution of Cu–Ni–Fe alloys,** *Acta Met.* **18,** *No. 5, 485–498 (May 1970).*

Key words: Alloys; Cu; Fe; metallurgy; Mössbauer effect; Ni.

Iron Mössbauer effect data are presented for a series of Cu–Ni–Fe alloys containing from 0 to 53 atm.% Ni and from 0.5 to 8 atm.% Fe. We consider the problem of interpreting the complex Mössbauer effect spectra in these alloys.

Berry, V. M., Sage, B. H., **Phase behavior in binary and multicomponent systems at elevated pressures: *n*-pentane and methane-*n*-pentane,** *Nat. Bur. Stand. (U.S.), Nat. Stand. Ref. Data. Ser. 32, 73 pages (June 1970). 70 cents, SD Catalog No. C13.48:32.*

Key words: Evaluated data; liquid-vapor equilibria; methane-*n*-pentane system; *n*-pentane; thermodynamics.

This paper, which is concerned with the critical evaluation of data on the phase behavior of binary systems, consists of three parts. In the first part the rationale of the evaluation process used is discussed, in the second the behavior of *n*-pentane, and in the third the behavior of the system methane-*n*-pentane.
The properties of *n*-pentane considered are the critical constants and the vapor pressures and densities of the saturated coexistent phases as functions of temperature. For the methane-*n*-pentane system the compositions and densities of the coexisting phases are given as functions of temperature and total pressure. Data for the unique states of the two-component system are also presented.
Discussions are given of the reliability of the selected values and of the differences between the selected values and various measured values.

Boesch, L., Napolitano, A., Macedo, P. B., **Spectrum of volume relaxation times in $B_2O_3$,** *J. Am. Ceram. Soc.* **53,** *No. 3, 148–153 (1970).*

Key words: Activation energy; annealing; Arrhenius behavior; $B_2O_3$ glass; distribution of relaxation times; relaxation times; volume relaxation times.

Time-index of refraction isotherms were measured for $B_2O_3$ glass starting from both a high and low temperature in the transformation region. The equilibrium values obtained from both types of approach curves were identical, showing that, as in the case of the density values, the equilibrium index curve as a function of temperature for this glass is not a straight line. The two relaxation time (crossover) model was applied to $B_2O_3$ glass and fitted the data as well as it did in previously described experiments with BSC and $GeO_2$ glasses. The reverse crossover which had been predicted by the model was experimentally confirmed with the $B_2O_3$ glass. The spectrum of relaxation times was found to narrow with decreasing temperature, indicating the approach to another region of single relaxation associated with the low temperature Arrhenius region. The relaxation times found for the low temperature crossover were in good agreement with those from the high temperature curves, indicating complete linearity in the experiments. The spectrum of relaxation times was investigated and was found to be slightly asymmetrical at constant pressure and very asymmetrical at constant volume.

Boswarva, I. M., **Semiempirical calculations of ionic polarizabilities and van der Waals potential coefficients for the alkaline-earth chalcogenides,** *Phys. Rev. B.* **1,** *No. 4, 1698–1701 (Feb. 15, 1970).*

Key words: Alkaline earth chalcogenides; electronic polarizabilities; Lorentz factor; oxides; sulfides; van der Waals coefficients.

Electronic polarizabilities for the ions of the alkaline earth chalcogenides have been calculated by assuming an additivity law within the family of salts and a Lorentz factor of $4\pi/3$ and using experi-

mental refractive indices and interionic distances. It is shown that the additivity assumption is well obeyed and the Lorentz factor value of $4\pi/3$ the best fit to the data. Each polarizability obtained has been related to a mean excitation or characteristic energy for the ion and hence the coefficients of the dipole-dipole and dipole-quadrupole terms of the van der Waals interaction energy derived.

Branscomb, L. M., **The photoionization of one- and two-electron atoms,** (*Proc. Sommerfeld Centennial Memorial Meeting, Munich, Germany, Sept. 10–14, 1968*), *Chapter in Physics of the One- and Two-Electron Atoms, F. Bopp and H. Kleinpoppen, Ed., pp. 669–699 (North Holland Publ. Co., Amsterdam, The Netherlands, 1969).*

Key words: Review of photoionization of hydrogen; helium and their ions.

Major advances in the physics of photoionization of one- and two-electron atoms (the isoelectronic series starting with H and $H^-$) are reviewed, with an emphasis on the extent to which theory and experiment are independently reliable and relatively in agreement. Great progress has been made in the last ten years in both theory and experiment because of a number of relatively recent developments: extremely accurate two-electron wave functions and photoionization cross section calculations, made possible by the computer; crossed beam methods for photoionization studies; the use of synchrotron radiation as an ultraviolet continuous light source; the development of the theory of autoionizing states and resonances; the use of high energy resolution electron scattering experiments in the energy range of Born approximation validity to study the distribution of oscillator strength in the atomic continuum. A number of interesting problems, however, remain unsolved.

Braun, W., Bass, A. M., Pilling, M., **Flash photolysis of ketene and diazomethane: the production and reaction kinetics of triplet and singlet methylene,** *J. Chem. Phys.* **52,** *No. 10, 5131–5143 (May 15, 1970).*

Key words: Absoulte reaction rates; diazomethane; flash photolysis; ketene; kinetics; methylene $CH_2$; vacuum UV.

Ketene and diazomethane have been flash photolyzed in their strongest absorption continua in the vacuum ultraviolet and far ultraviolet. Triplet methylene was monitored by kinetic spectroscopy at 141.5 nm. Singlet methylene was not observed directly, but the growth of the triplet absorption as a function of inert-gas pressure indicates that singlet methylene was the major primary product in both the ketene and diazomethane systems. Various inert additives quantitatively quenched the singlet to the triplet state, while reactive additives were able to intercept the singlet before quenching occurred. A number of reactions and deactivations involving singlet methylene ($^1CH_2$) and triplet methylene ($^3CH_2$) have been investigated at 298 °K, and their rate constants are listed below ($cm^3$ molecule $\cdot^{-1}$ second$^{-1}$):

| | | |
|---|---|---|
| $^3CH_2 + {}^3CH_2 \rightarrow C_2H_2 + H_2$ | $(5.3 \pm 1.5) \times 10^{-11}$ | (1a), (1b) |
| $^1CH_2 + H_2 \rightarrow CH_4^* \rightarrow CH_3 + H$ | $(7.0 \pm 1.5) \times 10^{-12}$ | (2) |
| $^1CH_2 + H_2 \rightarrow {}^3CH_2 + H_2$ | $< 1.5 \times 10^{-12}$ | (3) |
| $^1CH_2 + CH_4 \rightarrow C_2H_6^* \rightarrow CH_3 + CH_3$ | $(1.9 \pm 0.5) \times 10^{-12}$ | (4) |
| $^1CH_2 + CH_4 \rightarrow {}^3CH_2 + CH_4$ | $(1.6 \pm 0.5) \times 10^{-12}$ | (5) |
| $^1CH_2 + He \rightarrow {}^3CH_2 + He$ | $(3.0 \pm 0.7) \times 10^{-13}$ | (11) |
| $^1CH_2 + Ar \rightarrow {}^3CH_2 + Ar$ | $(6.7 \pm 1.3) \times 10^{-13}$ | (12) |
| $^1CH_2 + N_2 \rightarrow {}^3CH_2 + N_2$ | $(9.0 \pm 2.0) \times 10^{-13}$ | (13) |
| $^3CH_2 + H_2 \rightarrow CH_3 + H$ | $< 5 \times 10^{-14}$ | (18) |
| $^3CH_2 + CH_4 \rightarrow CH_3 + CH_3$ | $< 5 \times 10^{-14}$ | (19) |

The absolute reaction rates for the singlet are apparently independent of the source (i.e., ketene or diazomethane), suggesting that the reactions occur via vibrationally cold singlet methylene. No evidence was found for deactivation of the triplet to the singlet, indicating that the energy difference between the two states is greater than $kT(T = 298\ °K)$.

Brenner, A., Sligh, J. L., **Electrodeless electrolysis,** *J. Electrochem. Soc.* **117,** *No. 5, 602–608 (May 1970).*

Key words: Electrodeless electrolysis; electrolysis; electrolysis of electron beam electrolysis; electrolysis of glass; fused salts; glow discharge.

Solid ionic conductors and fused salts were electrolyzed without contact of solid electrical leads. The current was carried to the materials to be electrolyzed either by means of electrons emitted by a hot filament or by a glow discharge. The materials were made the separating wall between the anode and cathode compartments of an apparatus constructed of glass or fused silica.

Electrolysis of glass produced a white opaque material which did not seem to differ chemically from the original glass. Dendrites of several metals were obtained in the glow electrolysis of fused salts. The latter process resembled conventional electrolysis with metal electrodes and was not similar to the glow discharge electrolysis of aqueous electrolytes.

Broadhurst, M. G., Mopsik, F. I., **Bulk modulus and Grüneisen parameters for linear polymers,** *J. Chem. Phys.* **52,** *No. 7, 3634–3641 (Apr. 1, 1970).*

Key words: Anderson-Grüneisen parameter; bulk modulus; compressibility; Grüneisen constant; pair potential; paraffins; polyethylene; polymers; pressure; volume.

Expressions are derived for the isothermal bulk modulus $B_T$ and Anderson-Grüneisen parameter $\sigma$ for a simple two dimensional bundle-of chains model where parallel nearest neighbor chains are assumed to interact with a simple separation-dependent potential. Bulk modulus data for general linear polymers are examined and shown to be essentially temperature independent at constant volume in accord with the model. The theory is shown to predict quite accurately for reasonable assumed pair potentials both $B_T$ and $\sigma$ of high density polyethylene and *n*-paraffins with no adjustable parameters.

The values of $\sigma$ obtained for polyethylene from $B_T$ data are in excellent agreement with those reported from ultrasonic data. The analysis is also shown to provide a sensitive measure of the form of the effective chain pair potential near its minimum.

Bullis, W. M., Editor, **Methods of measurement for semiconductor materials, process control, and devices,** *Quarterly Report October 1 to December 31, 1969 Nat. Bur. Stand. (U.S.),* Tech. *Note 527, 60 pages (May 1970) 60 cents, SD Catalog No. C13.46:527.*

Key words: Alpha detectors; aluminum wire; carrier lifetime; die attachment; electrical properties; epitaxial silicon; gamma detectors; germanium; gold-doped silicon; metallization; methods of measurement; microelectronics; microwave devices; nuclear radiation detectors; resistivity; semiconductor devices; semiconductor materials; semiconductor process control; silicon thermal resistance; thermographic measurements; ultrasonic bonder; wire bonds.

This quarterly progress report, sixth of a series, describes NBS activities directed toward the development of methods of measurement for semiconductor materials, process control, and devices. Principal emphasis is placed on measurement of resistivity, carrier lifetime, and electrical inhomogeneities in semiconductor crystals; evaluation of wire bonds, metallization adhesion, and die attachment; and measurement of thermal properties of semiconductor devices and electrical properties of microwave devices. Work on related projects on silicon nuclear radiation detectors and specification of germanium for gamma-ray detectors is also described. Supplementary data concerning staff, standards committee activities, technical services, and publications are included as appendixes.

Bullough, R., Simmons, J. A., **On the deformation of an imperfect solid, Chapter 5 in Physics of Strength and Plasticity,**

*A. S. Argon, Ed., pp. 47–63 (Massachusetts Institute of Technology Press, Cambridge, Mass., 1969).*

Key words: Continuity equations; continuous distribution of dislocations; defect measures; deformations of connections; deformations of tensors; dislocations; imperfect continuum; non-linear elasticity; non-linear strain measures; point defects.

A new formalism is presented for treating the non-linear aspects of the elastic theory of continuous distributions of dislocations and point defects. The concept of deformations of tensors and connections associated with an imperfect continuum is introduced and used to obtain relevant continuity equations together with expressions for the charge of defect content without invoking either "non-Euclidean spaces or anholonomic coordinates". Attention is drawn to the fact that the ordinarily used Cauchy strain is a generally invalid strain measure and the theory is therefore developed using both the correct Green strain and other appropriate strain measures. The correct defect measure is the Cauchy torsion tensor shown to be, in general, independent of the analogous Green torsion tensor which occurs in the continuity equation for the Green strain. The consequent difficulties are discussed and procedures for solving two new types of non-linear defect problems are given.

Bur, A. J., **Extrapolation to single-relaxation-time behavior in solutions of poly(*n*-butylisocyanate),** *J. Chem. Phys.* **52,** *No. 7, 3813–3819 (Apr. 1, 1970).*

Key words: Dielectric constant; dielectric relaxation time; dipole moment; distribution of molecular weights; distribution of relaxation times; poly(*n*-butylisocyanate); rodlike molecule; single relaxation time.

The dielectric relaxation time of rodlike poly (*n*-butyl isocyanate) (PBIC), $(-CO-NR-)_n$ where $R = C_4H_9$, has been observed for dilute solutions as a function of the polydispersity in the PBIC molecular weight. The mode of relaxation is rotation about the minor axis of the rodlike molecule (end-over-end rotation). The dielectric relaxation time for this mode is a sensitive function of molecular weight, and a distribution of relaxation times $\Phi(\tau)$ is observed whenever a distribution of molecular weights $\Psi(M)$ is present. A one-to-one correspondence between $\Phi(\tau)$ and $\Psi(M)$ is established by observing the half-width $W/2$ of the dielectric dispersion on a log frequency plot as a function of the ratio $M_w/M_n$ where $M_n$ and $M_w$ are the number and weight averages of $\Psi(M)$. Extrapolation of the $W/2$ vs $M_w/M_n$ data to the monodispersed case ($M_w/M_n = 1.0$) is carried out in order to determine that a monodispersed sample has a single relaxation time. In the region $M_w/M_n = 1.0$ to 1.6, the experimentally observed $W/2$ is in good agreement with $W/2$ calculated for the end-over-end relaxation of a rodlike molecule whose dipole moment is proportional to its molecular weight. The distribution $\Psi(M)$ may be obtained from the observed $\Phi(\tau)$ if it can be assumed that all molecules have the same conformation.

Burgess, A., Hummer, D. G., Tully, J. A., **Electron impact excitation of positive ions,** *Phil. Trans. Roy. Soc. London,* **A.266,** *No. 1175, 225–279 (Apr. 23, 1970).*

Key words: Cross section; electron impact excitation; ionized helium; positive ion.

Non-relativistic Coulomb-Born-Oppenheimer reactance matrices and cross sections are given for all transitions between the 1*s*, 2*s* and 2*p* states in $He^+$ and in hydrogen-like ions of large nuclear charge. From these results some cross sections for intercombination transitions in highly charged non-hydrogenic ions are estimated.

Burke, P. G., Gallaher, D. F., Geltman, S., **Electron scattering by atomic hydrogen using a pseudo-state expansion. I. Elastic scattering,** *J. Phys. B. (Proc. Phys. Soc.)* **2,** *1142 (1969).*

Key words; Close coupling; elastic scattering; electron; hydrogen atom; polarizability; pseudo-states.

A modified close coupling expansion has been developed and applied to calculate elastic electron-hydrogen atom scattering phase shifts. This expansion into a complete, discrete, orthonormal basis set is a variant of the more usual close coupling expansion into eigenstates of the target Hamiltonian. We retain the first few hydrogen atom eigenstates and augment these terms with pseudo-states chosen, in our particular case, to incorporate fully the ground state polarizability of the hydrogen atom. The resulting phase shifts are compared, where possible, with those obtained in the most accurate variational calculations available, and they indicate a distinctly improved convergence over those obtained in the close coupling expansion.

Burke, R. W., **Exchange reactions of ternary ion association complexes directly in the organic phase,** *Talanta* **17,** *240–242 (1970).*

Key words: Directly in organic phase; exchange reactions; spectrofluorometric; spectrophotometric; ternary ion association complexes; trace.

A unique approach has been developed that combines the advantages of solvent extraction with the inherently high sensitivities afforded through the incorporation of large organic dye cations into ternary ion association complexes containing the metal ion of interest. Basically, the new technique involves the formation of a complex of the type $[ML_x]^-R^+$ where $R^+$, initially, is either a non-colored or a non-fluorescent organic cation. Following extraction of $[ML_x]^-R^+$ a second $R_1^+$ is added directly to the organic phase which is capable of exchanging with the first $R^+$ group. In this instance, however, $R_1^+$ is purposely selected to be highly colored or fluorescent, thereby yielding the highly colored or fluorescent complex $[ML_x]^-R_1^+$. Unreacted $R_1^+$ is readily back-extracted, leaving only the dyecomplex in the organic phase. The determination of gold and uranium is described to illustrate the approach.

Burke, R. W., Deardorff, E. R., **Simultaneous spectrophotometric determination of cobalt, nickel and copper and 2,3-quinoxaline-dithiol,** *Talanta* **17,** *255–264 (1970).*

Key words: Aqueous ethanol; cobalt, copper, nickel; colored complexes; least squares treatment data; simultaneous spectrophotometric; 2,3-quinoxalinedithiol.

In aqueous ethanol, cobalt, nickel and copper react instantaneously with 2,3-quinoxalinedithiol at pH 2 to form strongly colored complexes exhibiting absorption maxima at 510 nm, 610 and 665 nm, and 625 nm, respectively. At pH 6 the reaction of copper can be virtually eliminated while the cobalt and nickel reactions show only small decreases in sensitivity. This combined behavior has been made the basis of a rapid method for the simultaneous determination of these three elements. The absorbances of the mixed complexes have been found additive for all possible combinations of elements in which the individual concentrations have been varied from approximately 0.1 to 1 ppm. A least squares treatment of the pertinent spectrophotometric data has yielded a series of constants from which the concentration of one, or all, of the elements can be calculated easily. The procedure has been applied to the analysis of complex ferrous and aluminum alloys with excellent success. The standard deviation of the method is less than 2% and, based on the analyses of seven synthetic solutions and four NBS Standard Reference Materials, systematic errors appear to be negligible.

Caswell, R. S., Danos, M., **On the accuracy of the adiabatic separation method,** *J. Math. Phys.* **11,** *No. 2, 349–354 (Feb. 1970).*

Key words: Adiabatic approximation; adiabatic separation method; coupled oscillators; matrix diagonalization; nuclear collective model.

Numerical experiments, performed for a model of two strongly coupled oscillators, indicate that the adiabatic separation method yields accurate results even where the condition of adiabaticity is violated to a very high degree, except in those cases where two levels are degenerate in the adiabatic approximation. An accurate solution for those cases can be obtained by diagonalizing the $2 \times 2$ Hamiltonian submatrix built on the two degenerate adiabatic states. It is conjectured that the adiabatic separation method can be expected quite generally to yield highly accurate results at least for states belonging to the discrete spectrum.

Christensen, R. G., Hoeve, C. A. J., **Comparison between theoretical and experimental values of the volume changes accompanying rubber extension,** *J. Polymer Sci.* **8,** *Part A-1, 1503–1512 (1970).*

Key words: Dilatometer; free energy; intramolecular interactions; intermolecular interactions; rubber elasticity; thermodynamics; volume change.

The molecular theory of rubber elasticity assumes the free energy to consist of two parts: a liquid-like free energy that is governed by intermolecular interactions and is independent of strain at constant volume and an intramolecular interaction free energy equal to the sum of the free energies of the chains making up the network. The volume increases of rubber samples as a function of their length were found to be considerably larger than predicted by the molecular theory. Therefore, contrary to common belief, the values of $(\partial E/\partial L)_{V,T}$ may not be related solely to changes in intramolecular interactions with extension. Also, the usual procedure to obtain values of $(\partial E/\partial L)_{V,T}$ from measurements of $(\partial f/\partial T)_{p,L}$ with the aid of the molecular theory is not strictly correct.

Cooper, M. J., **Critical indices of the Z–L polymer folding transition,** *J. Chem. Phys. Letter* **52,** *No. 1, 473–474 (Jan. 1, 1970).*

Key words: Critical indices; critical phenomena; phase transition polymer crystallization; Zwanzig-Lauritzen model.

The critical indices for the Zwanzig-Lauritzen polymer crystallization transition are identified and shown to satisfy the thermodynamic equalities.

Coxon, B., **Model parameters for the analysis of skew conformations of carbohydrates by p.m.r. spectroscopy,** *Carbohydrate Res.* **13,** *321–330 (1970).*

Key words: Carbohydrates; conformations; coupling constants; proton resonance; ribopyranose; skew.

The p.m.r. spectrum of 3-*O*-benzoyl-1,2,4-*O*-benzylidyne-α-D-ribopyranose (**1**) at 100 MHz has been analyzed by an iterative, least-squares method. The resulting geminal, vicinal, and long-range coupling-constants have been correlated with the stereochemistry of the locked skew conformation of **1**, and used to test the applicability of equations that relate coupling constant to dihedral angle. The mean deviation of the proton–proton dihedral angles as calculated from a Karplus equation from those measured from a molecular model was 11°.

Coyle, T. D., **Silica, Kirk-Othmer Encyclopedia of Chemical Technology,** *2nd Edition, 18, 46–61 (1969).*

Key words: Silica; silicon dioxide.

An introduction is given to the properties of silicon dioxide, including aspects of structure and bonding, the forms of silica and their interconversions, and the chemical properties and reactions of the material.

Cuthill, J. R., **A soft x-ray spectrometer with improved drive,** *Rev. Sci. Instr.* **41,** *No. 3, 422–423 (Mar. 1970).*

Key words: Lubrication in vacuum; soft x-ray spectrometer; spectrometer drive.

The spectrometer described is a grazing incidence grating instrument with an improved drive system for moving the electronic detector around the Rowland circle. In this system the lead screw driving the detector always lies along a chord of the Rowland circle joining the grating and the detector. With this design there is less chance of error due to flexure of the components than in previous designs, and the resolution of the spectrometer is constant in wavelength.

Diamond, J. J., Editor, **Bibliography on the high temperature chemistry and physics of materials, January, February, March, 1970,** *Nat. Bur. Stand. (U.S.), Spec. Publ. 315–5, 82 pages (Apr. 1970) 75 cents, SD Catalog No. C13.10:315–5.*

Key words: Bibliography, high temperature; chemistry, high temperature; high temperature chemistry; materials properties; research at high temperatures; thermophysical properties.

The bibliography consists of references to research involving temperatures above 1000 °C, which were noted by the Contributors during the above 3-month period. Since this is intended primarily as a current-awareness bibliography, there is no cross-referencing or indexing. This issue contains about 750 references roughly grouped under fifteen subject headings.

DiMarzio, E. A., Guttman, C. M., **Separation by flow,** *Macromolecules* **3,** *No. 2, 131–146 (Mar.–Apr. 1970).*

Key words: Chromatography; gel permeation chromatography; particle separation; polymer separation.

Dilute solutions of finite size particles undergoing Brownian motion and flowing through a capillary have average velocities which depend on the particle size. Thus one can obtain a separation of particles of different sizes due to fluid flow. The elution volumes of suspended particles or polymers are derived for various tube geometries. Following Taylor, the effects of diffusional broadening of the volume elution peak for finite size particles are discussed and a criteria for separation is given. It is found that particles very similar in size can always be separated. A scheme for separation by flow on a continuous basis is proposed.

Eisele, J. W., Technical Standards Coordinator, **Types and sizes of forms for one-way concrete joist construction,** *Nat. Bur. Stand. (U.S.), Prod. Stand. 16–69, 16 pages (June 1970), 10 cents, SD Catalog No. C13.20/2:16–69. Supersedes NBS Simplified Practice Recommendation 87–32.*

Key words: Concrete; floor and roof; forms; joist; one-way.

This Product Standard covers four types of forms for one-way *concrete joist construction*[1,2] and standard sizes for these types. Definitions of concrete joist construction and one-way joist construction are provided under Section 4.

Engen, G. F., **An evaluation of the "back-to-back" method of measuring adaptor efficiency,** *IEEE Trans. Instr. Meas.* **IM-19,** *No. 1, 18–22 (Feb. 1970).*

Key words: Adaptor; adaptor efficiency; adaptor evaluation; power measurement.

The problem of adaptor evaluation is of considerable interest in the UHF and microwave art where, because of the several different types of transmission line in common use, there is a frequent need to extend an established measurement capability in one type of line to other types of lines, e.g., from rectangular waveguide to coax.
In power and noise calibrations, it is the adaptor *efficiency* which is usually of interest, and one indication of the adaptor losses may be obtained by connecting an identical pair "back-to-back" and measuring the insertion loss of the combination by the usual techniques. If, then, the losses are assumed to divide equally between the two, the efficiency is thereby determined.
As a practical matter, the losses do not, in general, divide equally which leads to an error whose evaluation is the subject of this paper. In particular it is shown that the method is capable of good accuracy provided that the assumed identity of the two adaptors is satisfied.

Evenson, K. M., Wells, J. S., Matarrese, L. M., **Absolute frequency measurements of the $CO_2$ cw laser at 28 THz (10.6 μm),** *Appl. Phys. Letters* **16,** *No. 6, 251–253 (Mar. 15, 1970).*

Key words: $CO_2$ laser; CW laser absolute frequency measurement; $H_2O$ laser; harmonic generation; high frequency mixing; metal on metal diode.

The two highest C–W absolute frequency measurements as yet reported are described. Frequencies of the P(18) and P(20) 10.6 μm lines from a CW $CO_2$ laser were found to be 28.359800 THz and 28.306251 THz ± 0.000025 THz, respectively. The frequencies were measured by beating each of these lines with 3.8 (78 μm) and 10.7

THz (28 $\mu$m) radiation from a water vapor laser in a tungsten-on-nickel point contact diode.

Evenson, K. M., Wells, J. S., Matarrese, L. M., Elwell, L. B., **Absolute frequency measurements of the 28- and 78-$\mu$m cw water vapor laser lines,** *App. Phys. Letters* **16,** *No. 4, 159–161 (Feb. 15, 1970).*

Key words: Laser frequency measurement; 10.7 and 3.8 THz frequency mesurement; 28 and 78 micron water vapor laser.

Frequencies of the 28 and 78 micron cw water vapor laser lines were found to be 10.718065 ± .000002 THz and 3.821769 ± .000002 THz by beating each of these radiations with the 337 and 373 radiation from an HCN laser in a metal on metal point contact diode. The frequencies of the HCN laser were in turn measured by beating the 337 micron radiation with 74 GHz radiation and by measuring the 337 to 373 difference.

Faison, T. K., Jr., Davis. J. C., Achenbach, P. R., **Performance of louvered devices as air mixers,** *Nat. Bur. Stand. (U.S.), Bldg. Sci. Ser. 27, 22 pages (Mar. 1970) 30 cents, SD Catalog No. C13.29/2:27.*

Key words: Effectiveness; forced mixing; mixing device; pressure drop; temperature; uniformity.

As part of a study of evaluating methods for reducing thermal gradients within the cross section of an air stream, three louvered mixing devices were investigated. Each of these devices was found to be capable of reducing the cross-sectional nonuniformity of air temperature to a few percent of the entering value. The three devices covered in this report contain combinations of louvers (directing vanes) and baffles as mixing elements. Two of the devices were designed at the National Bureau of Standards; the third was a modification of a previous design. The three mixers (the lourvered strip, the concentric louvers, and the louvered-baffle) required 4.75, 3.8, and 3.0 duct diameters, respectively, to reach a mixing effectiveness level of 97 percent. The mixing effectiveness of the louvered strip and concentric louver models was independent of the approach velocity, whereas the effectiveness of the louver-baffle model was somewhat dependent on the approach velocity. The pressure drops accompanying air flow through the mixers, expressed as multiples of the velocity head of the entering air, were approximately 7, 5, and 38 for the louvered strip, concentric louver, and louver-baffle mixers, respectively.

Fishman, L., Mountain, R. D., **Activity coefficients of solutions from the intensity ratio of Rayleigh to Brillouin scattering,** *J. Phys. Chem.* **74,** *No. 10, 2178–2182 (May 14, 1970).*

Key words: Activity coefficients; binary mixture; brillouin scattering; fluctuations; light scattering from solutions; Rayleigh scattering; thermal relaxation; volume viscosity.

The ratio of the intensity of Rayleigh to Brillouin scattered light for a binary mixture with internal degrees of freedom is determined by calculating the frequency spectrum of fluctuations in concentration, temperature and pressure. Thermodynamic fluctuation theory and linearized hydrodynamic equations, modified to include the internal degrees of freedom through a frequency dependent volume viscosity, are employed in the calculation. The intensity ratio is of interest as it may be used to determine activity coefficients. A method of doing so when the system contains internal degrees of freedom is described.

Fraker, A. C., Ruff, A. W., Jr., **Microstructural studies of 7075 Al-relation to the directional sensitivity for stress corrosion cracking,** *Corrosion Sci.* **10,** *191–195 (1970).*

Key words: Aluminum alloys; corrosion; dislocations; electron microscopy precipitates; stress corrosion cracking.

The directional sensitivity to stress corrosion cracking (SCC) of commercial 7075 aluminum has been studied. Transmission electron micrographs show the dislocation and precipitate distribution to be the same in the three principal directions and relatively homogeneous from grain boundaries to the inner grain regions. It is concluded that the precipitate and dislocation structures are not responsible for the directionality observed in SCC and that the sensitivity can be attributed to grain shape anisotropy and internal boundaries.

Franklin, A. D., Bennett, H. S., Editors, **ARPA–NBS program of research on high temperature materials and laser materials. Reporting Period July 1 to December 31, 1969,** *Nat. Bur. Stand. (U.S.), Tech. Note 531, 75 pages (June 1970) 70 cents, SD Catalog No. C13.46:531.*

Key words: Band structure; chemical analysis; copper; creep; crystal defects; crystal growth; diffusion; evaporation; glass; high temperature materials; inhomogeneities in glass; laser damage; laser glass; lasers; mass transport; materials properties; metal properties; optical properties; opto-elastic properties; oxides; polymers; ruby; titanium; transition.

Brief reviews are given of work performed during the period July 1 to December 31, 1969, on a number of projects concerned with High Temperature Materials and with Laser Materials. Under the High Temperature Materials heading, topics include diffusion of oxygen in oxides, growth of $Al_2O_3$ crystals by chemical vapor deposition, the electronic structure of transition metal borides and related compounds, the optical constants of titanium, high temperature creep in copper, and the mechanism of volatilization of polymers and long-chain compounds. Work on Laser Materials includes measurement of bulk optical and elastic properties of Laser Materials, a study of the "orange" degradation of ruby, measurements of sub-crystal misalignment in ruby, damage in glass induced by high-energy laser pulses, chemical analyses for ruby and Nd-doped laser glasses, and preliminary studies on detection of submicroscopic inhomogeneities in glass.

Frederikse, H. P. R., **The electronic band structure of strontium titanate: Theory and experiment** *(Proc. Conf. International Advanced Study Institute: Electronic Structures in Solids, Chania, Crete, Greece, June 30–July 14, 1968), Chapter in Electronic Structures in Solids, pp. 259–269 (Plenum Press, New York, N.Y., 1969).*

Key words: Electronic bandstructure; oxides; semiconductors; strontium titanate; transition metal compounds; transport measurements.

The approach used for calculating the electronic energy bands of $SrTiO_3$ is indicated. A number of experiments designed to test the result of this calculation is discussed. Among these are both transport measurements and optical investigations.

Furukawa, G. T., Saba, W. G., Sweger, D. M., Plum, H. H., **Normal boiling point and triple point temperatures of neon,** *Metrologia* **6,** *No. 1, 35–37 (Jan. 1970).*

Key words: Boiling point; neon; triple point.

The normal boiling point and triple point temperatures and the triple point pressure of neon were found to be 27.096 ± 0.001 K and 24.553 ± 0.001 K and 43332 ± 13N/m² (325.02 ± 0.10 mm Hg, (0 °C)), respectively. (The temperatures are in terms of the NBS–1955 provisional temperature scale. The figures after the ± symbol indicate estimated uncertainties.) The triple point pressure is in accord with the more recent values, but the normal boiling point and triple point temperatures deviate significantly from those of previous investigators.

Gadzuk, J. W., **Coupled surface-plasmon modes in metal-thin-film-vacuum sandwiches,** *Phys. Rev. B,* **1,** *No. 3, 1267–1269 (Feb. 1, 1970).*

Key words: Adsorption; electron emission; junctions; low energy electron diffraction; plasma oscillations.

The normal surface plasmon modes for a thin layered plasma bounded on one side by a semi-infinite plasma and on the other side by a vacuum are determined. The characteristic frequencies of the coupled modes resulting from surface oscillations of the plasma-plasma interface and the plasma-vacuum interface are found.

Gadzuk, J. W., **Resonance-tunneling spectroscopy of atoms adsorbed on metal surfaces: theory,** *Phys. Rev. B.* **1,** *No. 5, 2110–2129 (Mar. 1, 1970).*

Key words: Adsorption; atomic spectroscopy; electron tunneling; surface physics.

Using a perturbational approach, the theory of resonance tunneling of field emitted electrons through atoms adsorbed on metal surfaces, first treated by Duke and Alferieff, is considered. It is shown how one can proceed from the observed total energy distributions to information concerning the energy level spectrum of the atom perturbed by the metal surface. The major alteration of the spectrum manifests itself in a shift and lifetime broadening of the atomic energy levels due to configuration interactions with the continuum of metal states. In past work, this shift and broadening have been theoretically calculated by various workers. Theories have also been advanced for calculating dipole moments and consequently work function changes and binding energies in which the final expressions for these quantities require knowledge of the perturbed atomic energy level scheme.
The plan in the present paper is to present a method of analyzing the data obtained in resonance tunneling spectroscopy so that values for the shift and broadening of the energy levels can be obtained. To proceed towards this end a liberal mixing of mathematical rigor and physical intuition is invoked. We believe however that the present approach maintains sufficiently close contact with the physics of the processes involved and thus because of its transparency is a potentially more valuable tool than past theories.
The first experimental data of resonance tunneling in field emission, obtained by Plummer and reported on in the preceding paper, is analyzed within the context of the present theory. This data includes tunneling through single zirconium atoms in which a single broad ground state level is seen, tunneling through barium atoms in which both a broad ground state of $6s^2$ character and two narrow excited $6s5d$ states are seen, and tunneling through calcium in which a somewhat narrow $4s4p$ excited state is seen. Most aspects of the data are satisfactorily accounted for in the present theory and the observed shifts and broadenings of the levels are in good agreement with past calculations.

Ginnings, D. C., Editor, **Precision measurement and Calibration. Selected NBS Papers on heat,** *Nat. Bur. Stand. (U.S.), Spec. Publ. 300, Vol. 6, 387 pages (February 1970) $5.00, SD Catalog No. C13.10:300/v.6.*

Key words: Bomb calorimetry; calorimetric design principles; calorimetric theory; calorimetric methods; cryoscopic studies; differential thermal analysis; heat measurements; heat transfer; high temperature calorimetry; low temperature calorimetry; reaction calorimetry.

This volume is one of an extended series which brings together the previously published papers, monographs, abstracts, and bibliographies by NBS authors dealing with the precision measurement of specific physical quantities and the calibration of the related metrology equipment. The contents have been selected as being useful to the standards laboratories of the United States in tracing to NBS standards the accuracies of measurement needed for research work, factory production, or field evaluation.
Volume 6 contains reprints through 1968 covering the following topics: General Calorimetry and Techniques, Low Temperature Calorimetry, High Temperature Calorimetry, Reaction Calorimetry, and Heat Transfer.

Graminski, E. L., **The stress-strain behavior of accelerated and naturally aged papers,** *Tappi* **53,** *No. 3, 406–410 (Mar. 1970).*

Key words: Cross-linking; degree of crystallinity; extensional stiffness: natural and laboratory aging; stress-strain.

The extensional stiffness generally increases when paper is aged under accelerated conditions, indicating that either cross linking occurs or that the degree of crystallinity increases. Either of these processes could be responsible for the increase in wet-strength when paper is heated (3, 4, 5, 6). An increase in wet-strength also occurs in the course of natural aging, indicating that some similarity exists between accelerated and natural aging.

Gross, D., Natrella, M. G., **Interlaboratory comparison of the potential heat test method,** *Am. Soc. Testing Mater. Spec. Tech. Publ. 464, Fire Test Performance, pp. 127–152 (1970).*

Key words: Calorimetry; combustibility; fire tests; heat of combustion; interlaboratory tests; oxygen bomb; potential heat.

Quantitative measurements of the total heat release by selected building materials were made during an interlaboratory study of the Potential Heat Method. Seven of the eleven participating laboratories ranked the five materials in the same order, and a single ranking change for three other laboratories would yield identical rankings. The general magnitude of within-laboratory repeatability and between-laboratory reproducibility for composite materials of generally low potential heat are indicated by statistical analysis of the results.
Results are reported on the effect of the amount of combustion promoter used and on differences in the first and second phase values. A discussion is presented on the effects of material sampling and on certain features of the experimental procedure which require special care. A tentative test method standard, containing complete details of the test procedure, is included as an appendix.

Guildner, L. A., Stimson, H. F., Edsinger, R. E., Anderson, R. L., **An accurate mercury manometer for the NBS gas thermometer,** *Metrologia* **6,** *No. 1, 1–18 (Jan. 1970).*

Key words: Capacitance; diaphragm pressure transducer; environment; meniscus characteristics; mercury manometer; pressure; pressure regulator; vacuum joints; vacuum valves; wring tests.

A mercury manometer using capacitance sensing of meniscus positions has been refined to give an accuracy within 2 parts in $10^6$ of the pressure in the range from $1 \times 10^4$ to $1.3 \times 10^5$ N/m$^2$. The determination of pressure ratios is accurate within 1.5 parts in $10^6$ for pressures in the same range.

Haar, L., Sengers, J. M. H. L., **The solubility of condensed substances in dense gases, and the effect on *PVT* properties,** *J. Chem. Phys.* **52,** *No. 10, 5069 (May 15, 1970).*

Key words: Ammonia; dense gases; equation of state; hydrogen; mercury vapor; nitrogen; noble gases; solubility-enhancement; steam; Van der Waals' equation.

An analytic relation is derived in terms of the molecular interactions for the density dependence of the solubility of a liquid or solid in a dense gas. It is shown that previous analytical treatments of this problem cannot in general be extrapolated beyond low densities, and that the effect of the solubility enhancement on high density *PVT* measurements is much smaller than previously thought. The theory is applied to the case where the condensed material is liquid mercury. Solubility vs. density isotherms and the effect of the solubility on *PVT* measurements are obtained at 50, 150, 250, and 400 °C for the following gaseous species: He, $H_2$, Ne, Ar, Kr, Xe, $N_2$, $NH_3$, $H_2O$. The need for accurate experimental data at high gas densities to test further the essential features of the theory is discussed.

Hamer, W. J., DeWane, H. J., **Electrolytic conductance and the conductances of the halogen acids in water,** *Nat. Stand. Ref. Data Ser., Nat. Bur. Stand. (U.S.), 33, 37 pages (May 1970) 50 cents, SD Catalog No. C13.48:33.*

Key words: Conductances of HF, HCl, HBr, and HI; electrolytic conductance; theories of electrolytic conductance.

Definitions, symbols, general principles, and general laws related to the electrolytic conductance of aqueous solutions are presented. The general laws considered are Coulomb's law for charged bodies, Poisson's equation relating the electrostatic potential to charge distribution, and the Stokes and Oseen laws for the velocity of a sphere in a fluid medium. The relations between electrical resistance, electrical conductance, specific resistance, specific conductance, and equivalent conductance are set forth. Theoretical expressions for the equivalent conductance as derived by Debye, Onsager, and Fuoss are given in general form and in a somewhat more detailed fashion in an appendix. The general methods of treating the equivalent conductances of ionophores and ionogens, especially in regard

to the determination of the limiting equivalent conductance, the degree of ionic association, and the degree of ionic dissociation are discussed. Data on the equivalent conductances of the halogen acids, hydrofluoric, hydrochloric, hydrobromic, and hydriodic acids in water are given for a wide range of concentration and temperature.

Harvey, J. L., Brenner, F. C., **Tire use survey. The physical condition, use, and performance of passenger car tires in the United States of America,** *Nat. Bur. Stand. (U.S.), Tech. Note 528, 59 pages (May 1970) 60 cents, SD Catalog No. C13.46:528.*

Key words: Accident; review; survey; tire disablement; tire inflation; tire loading; tire pressure gages; tire use; tread wear.

This review summarizes the results of two surveys of the physical condition and use of passenger car tires in the continental U.S.A., conducted under contract for the Office of Vehicle Systems Research (OVSR) of the National Bureau of Standards (NBS) during the period June 1967 through May 1968.
Data and results are compared with those in four related reports recently published by the Traffic Institute of Northwestern University. The latter reports cover studies on the use, condition, and performance of passenger car tires on the Illinois Tollway during the period September 1966 through August 1967. Pertinent information from various other sources is also included.
Based on the compiled evidence, some conclusions are drawn concerning the physical condition, use, and abuse of passenger car tires in service during these years, particularly with regard to tread depth, inflation pressures, and degree of overloading. The various estimates of tire disablement rates are compared, and contributions of tires to motor vehicle accidents explored.
The authors make several recommendations directed toward upgrading the level of quality of passenger car tires in service, and reducing their abuse, with the hope and expectation that service performance will be improved, and contributions of tires to highway accidents reduced.

Heinrich, K. F. J., **Electron and ion microprobe analysis** *(Proc. 10th Symp. Electron, Ion, and Laser Beam Technology, Gaithersburg, Md., May 21–23, 1969) Chapter in Record of the 10th Symposium on Electron, Ion, and Laser Beam Technology, L. Martin, Ed., pp. 353–360 (San Francisco Press, San Francisco, Calif., 1969).*

Key words: Electron microprobe; ion microprobe; mass spectrography; microanalysis; scanning electron microscopy; x-rays.

This review covers the principles and development of electron probe microanalysis, with particular emphasis on recent developments. The double function of the instrument as a spectrograph and as a microscope is considered. The salient characteristics of the ion beam microprobe are also indicated.

Heinrich, K. F. J., Yakowitz, H., **Quantitative electron probe microanalysis: Uncertainty in the atomic number correction,** *Miktochim. Acta* **7,** *No. 1, 123–134 (Jan. 1970).*

Key words: Atomic number correction; Bethe's Law; electron backscatter; error propagation; mean ionization potential; microprobe analysis.

The atomic number effect in quantitative electron probe microanalysis has been considered from the point of view of error propagation. The results indicate that the chief cuases of analysis uncertainty are poorly known electron backscattering factors and mean ionization potential values. Operating variables such as working voltage or x-ray takeoffangle cannot be manipulated so as to reduce the effect of the uncertainties. However, the overall analysis uncertainty remains nearly constant over the entire range of working voltages practical for microanalysis.

Horn, W. A., **Optimal networks joining *n* points in the plane** *(Proc. IVth International Symp. The Theory of Traffic Flow, Karlsruhe, Germany, June 18–20, 1968), Chapter in Strassenbau und Strassenverkehrstechnik 86, W. Leutzbach and P. Baron, Ed., pp. 160–166 (Bundesminister fur Verkehr, Germany, 1969).*

Key words: Optimal interchange location; optimal networks; optimal road layout; planar graphs; planar networks; road location; Steiner's problem; the street-network problem; transportation theory.

This report develops a number of results on the problem of connecting $n$ points in the plane, with given travel demands between each pair, by a minimum-cost network. The critical assumptions are (a) constant construction costs per mile, (b) constant travel cost per mile per traveller, and (c) use of shortest paths in the network for all travel.
These results are adequate to give a complete solution when $n=3$. For this, the possible optimal network configurations are identified, each is shown actually to arise as the optimum for suitable combinations of problem data, and the computations necessary to choose among them are described. One of the results for general $n$ is an upper bound (roughly $n^4/4$) on the number of nodes, other than the original $n$ points, in an optimal network. Another is the determination of an explicit threshold, for the ratio of construction cost to travel cost, beyond which each "auxiliary node" will lie on exactly three links.

Hougen, J. T., **The calculation of rotational energy levels and rotational line intensities in diatomic molecules,** *Nat. Bur. Stand. (U.S.), Monogr. 115, 52 pages (June 1970) 55 cents, SD Catalog No. C13.44:115.*

Key words: Diatomic molecules; Hund's coupling cases; rotational levels; rotational line intensities; theoretical calculations.

Procedures are described, in this pedagogical monograph, for making quantum mechanical calculations of rotational energy levels and rotational line intensities in diatomic molecules. The procedures are illustrated by sample calculations. A familiarity with the material of this report should enable a practicing electronic spectroscopist to carry out, though in a rather mechanical way, his own theoretical calculations for molecules under experimental investigation. The material of this report is aimed at electronic spectroscopists who have had the equivalent of one semester of graduate-level quantum mechanics.

Hummer, D. G., **Spectral line formation by noncoherent scattering with a dipole phase-function,** *Astrophysical Letters* **5,** *1 (1970).*

Key words: Anisotropic scattering; limb darkening; noncoherent scattering; Rayleigh scattering; spectral line formation.

Results are presented for lines formed by atoms scattering photons with complete redistribution in frequency and a dipole (Rayleigh) phase function. For optical thicknesses on the order of unity the ratio of limb ($\mu \simeq 0.2$) to disc intensity for dipole scattering is about 5% larger than for isotropic scattering, at all frequencies. For larger optical thickness ($> 10^2$), the limb-to-disc ratio is about 2% lower for dipole than for isotropic scattering within a Doppler halfwidth of the line center and unity in the line wings. Some quantitative information is given on the angular distribution of the radiation field. An exact relation between two moments of the radiation field at the surface of a semi-infinite, isothermal medium is presented.

Jones, R. N., Huntley, L. E., **A precision, high frequency calibration facility for coaxial capacitance standards,** *Nat. Bur. Stand. (U.S.), Tech. Note 386, 27 pages (Mar. 1970), 35 cents, SD Catalog No. C13.46:386.*

Key words: Calibration; capacitance; capacitance, measurement; coaxial capacitance standards; impedance measurements, capacitance; standards; statistical control.

Using high frequency impedance standards which are fitted with precision coaxial connectors, and limiting calibrations to specific frequencies and impedance values, can contribute greatly toward improving measurement agreement and standardization. These advantages have been utilized in the development of a new and much improved calibration service for capacitance in the high frequency region. The service is for capacitances of 50, 100, 200, 500 and 1000 picofarads at 100 kHz, 1 MHz, and 10 MHz. This paper describes the

instrumentation used in the measurements and the method of data handling, and gives a detailed breakdown of the measurement uncertainties.

Kasen, M. B., **Grain boundary resistivity of aluminum,** *Phil. Mag.* **21,** *No. 171, 599–610 (Mar. 1970).*

Key words: Aluminum; electrical resistivity; grain boundaries; recrystallization; solute segregation; super-purity metals.

Residual resistivity at 4 K has been studied as a function of grain boundary area per unit volume in aluminum of two differing purities. A positive correlation between residual resistivity and boundary area was observed above a minimum boundary area per unit volume. The resistivity attributable to the presence of grain boundaries was found to reflect both the defect structure of the boundaries and the solute redistribution due to boundary segregation. Elimination of the solute effect yielded a specific boundary resistivity of $1.35 \pm 0.5 \times 10^{-12}$ ohm-cm² for pure boundaries. Evidence of a purification effect due to grain boundary segregation was noted.

Kose, V. E., Sullivan, D. B., **Influence of external noise on microwave-induced Josephson steps,** *J. Appl. Phys.* **41,** *No. 1, 169–174 (Jan. 1970).*

Key words: Electromagnetic noise; fundamental constant; Josephson effect; superconductivity.

The influence of fluctuations on microwave induced Josephson steps is treated phenomenologically and it is found that the center voltage of these steps is not shifted by the disturbance. Expressions governing the step shape are obtained for various noise spectra. The theory was checked by subjecting niobium point contact junctions to several forms of externally generated noise. The theory does not differentiate between internal and external noise sources, so that a number of the conclusions can be extended to intrinsic fluctuations.

Landgrebe, W. B., Mann, W. B., Schima, F. J., **The distribution of 70-kV prasodymium ions in iron foil and a technique for removing thin layers of iron,** *Intern. J. Appl. Radiation Isotopes* **21,** *No. 3, 169–171 (Mar. 1970).*

Key words: Chemical stripping; chemical stripping, citric acid; dispersion of ions; penetration profile; penetration profile in iron; prasodymium ion implantation; prasodymium profile in iron; prasodymium range in iron.

The NBS isotope separator has been used to implant barium-140, praseodymium-142 and thulium-170[m1] into iron foils for nuclear-orientation studies at low temperatures. In the case of praseodymium, stripping experiments were carried out to determine the depth of penetration. The profile of the beam was also determined.

Larson, W., Desch, R. F., Gillard, B. F., **Further analysis of the off-null versus power ratio method of attenuation measurement,** *IEEE Trans. Microwave Theory Tech.* **MTT-18,** *No. 2, 112–113 (Feb. 1970).*

Key words: Attenuation measurement; microwave; rotary-vane attenuator.

Analysis of calibration data of a rotary-vane attenuator has yielded improved agreement between the Off-Null and Power Ratio methods of attenuation measurement. A constant bias was discovered in the measured values of attenuation difference, and a procedure is described to correct for this bias. After the correction is applied, the average agreement between the two methods of measurements is improved an order of magnitude, namely, from a former 2.0 percent to 0.17 percent.

Lawton, R. A., **New standard of electric field strength,** *IEEE Trans. Instr. Meas.* **IM-19,** *No. 1, 45–51 (Feb. 1970).*

Key words: Antenna; electric field strength; measurement; standard field.

A new technique is presented for establishing a standard of field strength using a conducting sphere. An analysis is made to determine the current on the sphere as a function of the electric field strength of an incident plane wave, a method of measuring that current using electronic circuitry and an optical indicator within the sphere is described, and an intercomparison is made with an independent field-strength standard.
This technique is a significant improvement over previous techniques in that it permits the absolute determination of field strength with a maximum uncertainty of 1 percent or less at 30 MHz. This technique is applicable to a broad range of frequencies and field strengths.

Lawton, R. A., Allred, C. M., Hudson, P. A., **A wide-range CW power measurement technique,** *IEEE Trans. Instr. Meas.* **IM-19,** *No. 1, 28–34 (Feb. 1970).*

Key words: RF power, measurement; receiver calibration.

An accurate, wide range, power measurement technique is described which makes possible the determination of the net power delivered to a load of arbitrary impedance. A standard power meter operating at some arbitrary level is employed to fix the reference power level. All subsequent measurements consist of dimensionless ratios and can be obtained from precision attenuators.
The method is applicable to a very wide range of frequencies and was demonstrated at a frequency of 30 MHz with power measurements extending from $10^{-2}$ watts to $10^{-14}$ watts. Maximum uncertainties ranged from ± 0.5 percent to 1.5 percent.
This technique is applicable in the measurement of the sensitivity of very low level detectors, receivers, radiometers, etc.

Lutz, G. J., Editor, **Determination of the light elements in metals: A bibliography of activation analysis papers,** *Nat. Bur. Stand. (U.S.), Tech. Note 524, 66 pages (May 1970), 75 cents, SD Catalog No. C13.46:524.*

Key words: Boron; carbon; light elements; metals; nitrogen; oxygen; phosphorous; silicon; sulfur.

References to the Determination of the Light Elements in Metals using Activation Analysis are indexed according to the elements boron, carbon, nitrogen, oxygen, phosphorous, silicon and sulfur. The indexes are arranged by Element Determined and subdivided according to Matrices and Nuclear Reactions involved. An Author Index is included.

McLaughlin, W. L., **Photographic film dosimeters,** *Chapter in Manual on Radiation Dosimetry, N. W. Holm and R. J. Berry, Ed., pp. 387–394 (Marcel Dekker, Inc., New York, N.Y., 1970).*

Key words: Dosimetry; gamma rays; hypersensitization; internal image; latensification; photographic development; photolysis; physical development; printout; radiographic films; silver halides.

A recipe and response curves are given for several dosimetry films, and their interpretation of γ-ray exposures over a wide range is discussed. The procedures include using a number of special optical and chemical treatments, in order to broaden the conventional response from $3 \times 10^{-2} - 10^{3}$ roentgens to $10^{-3} - 10^{8}$ roentgens. The special treatments include: Physical development, latensification plus physical development, stabilization processing. The advantages and disadvantages of these methods are outlined.

McKinney, J. E., Oser, H. J., **Stability of acoustic waves within a viscous compressible heat-conduction fluid,** *J. Acoust. Soc. Am.* **47,** *No. 3, 781–785 (Mar. 1970).*

Key words: Absorption; acoustic propagation; fluids; Kirchhoff-Langevin; Navier-Stokes; stability; thermal conductivity; viscosity.

The question of stability of propagation of acoustic waves within a continuum of compressible, viscous, heat-conducting fluid has been investigated. From the location of the essential singularities of the complex propagation function the following stability criterion relating certain thermophysical properties has been obtained:

$$\frac{3(2-\gamma)}{4(1+3\nu/4\eta)P} \leq 1, \qquad \gamma > 1$$

where $P$ is the Prandtl Number, $\gamma$ is the ratio of specific heats, and $\nu$ and $\eta$ are the bulk and shear viscosities, respectively. According to the theory the above inequality must be obeyed for all passive fluids. Using experimental values for many different fluids, it appears to be obeyed, in general, except for the molten metals, including mercury, and, possibly, the superfluids.

McLaughlin, W. L., **Radiochromic dye-cyanide dosimeters,** *Chapter in Manual on Radiation Dosimetry, N. W. Holm and R. J. Berry, Ed., pp. 377–385 (Marcel Dekker, Inc., New York, N.Y., 1970).*

Key words: Cyanides; dosimetry; dyes; electron beams; reflection densitometry; spectrophotometry; triphenyl methane; x- and γ-rays.

Triphenyl methane dye cyanide solutions (liquids, gels, films, and papers) have been developed for high-range dosimetry ($10^3 - 10^8$ rads). A recipe for their preparations, dose calibration by calorimetry, and spectrophotometric readout is included. The systems are shown to be highly versatile for radiation processing dosimetry.

Mackay, D. R., Technical Standards Coordinator, **American Softwood Lumber Standard,** *Nat. Bur. Stand. (U.S.), Prod. Stand. 20–70, 26 pages (Jan. 1970), 35 cents, SD Catalog No. C13.20/2:20–70. Supersedes NBS Simplified Practice Recommendation 16–53.*

Key words: Grades; lumber; sizes; softwood, species, timber.

This Product Standard covers the principal trade classifications and sizes of softwood lumber for yard, structural, and shop use. It provides a common basis of understanding for the classification, measurement, grading, and grade marking of rough and dressed sizes of various items of lumber, including finish, boards, dimension, and timbers.

Madey, T. E., Yates, J. T., Jr., King, D. A., Uhlaner, C. J., **Isotope effect in electron stimulated desorption: oxygen chemisorbed on tungsten,** *J. Chem. Phys.* **52,** *No. 10, 5215–5220 (May 15, 1970).*

Key words: Adsorption; chemisorption; desorption; electron bombardment; isotope; oxygen; single crystal; tungsten.

Electron stimulated desorption (ESD) studies of oxygen chemisorbed on tungsten have revealed a large isotope effect in the desorption of ions. The probability of desorption of $^{16}O^+$ was found to be a factor of ~ 1.5 greater than the probability of desorption of $^{18}O^+$ upon bombardment of the adsorbed layer by 100 eV electrons. This observation is quantitatively consistent with the ESD mechanism proposed independently by Redhead and Menzel and Gomer. On the other hand, the small isotope effect observed in ESD "total" desorption does not agree with this mechanism; possible reasons for this are discussed.

Mahler, R. J., James, L. W., **Acoustic and magnetic effects involving the 19F nuclei in antiferromagnetic KMnF,** *J. Appl. Phys.* **41,** *No. 4, 1633–1636 (Mar. 15, 1970).*

Key words: Interaction; nuclear spin system; phonons; transferred hyperfine.

An interaction is discussed which can couple externally added phonons to spin 1/2 nuclei in an ordered magnetic material. This interaction allows phonons at one frequency (one-phonon), or phonons at two different frequencies (two-phonon) to interact with the spins resulting in the saturation of the nuclear spin system. The results of an experiment observing the two phonon-magnetic coupling are presented. To demonstrate the strength of the magnetic-phonon coupling, and to show that the observed two-phonon coupling is too strong to be an anharmonic phonon effect, a comparison is made between the one- and two-phonon magnetic coupling and the one- and two-phonon quadrupole coupling.

Messina, C. G., Hilsenrath, J., **Edit-insertion programs for automatic typesetting of computer printout,** *Nat. Bur. Stand. (U.S.), Tech. Note 500, 50 pages (Apr. 1970), 60 cents, SD Catalog No. C13.46:500.*

Key words: Applications; computers; computer-assisted typesetting; FORTRAN programs; KWIC index; phototypesetting; printing.

SETLST and KWIND are FORTRAN programs which accept a card deck or Fortran records on magnetic tape and insert the appropriate flags and shift symbols required by many of the "standard" typesetting programs associated with phototypesetting devices. The programs are specialized to the particular application; the typesetting device and associated programs; and to the desired typeface, by means of control cards and substitution tables supplied at run time. Examples are shown of applications to program listings, KWIC indexes, and normal computer output. When the input is in tabular form, the program permits more sophisticated operations including rearrangement, removal of trailing blanks, typeface changes between columns, etc. These programs can handle any records which can be read by a FORTRAN READ statement under an "A" format control.

Michaels, S., Green, M. S., Larsen, S. Y., **Equilibrium critical phenomena in fluids and mixtures: a comprehensive bibliography with key-word descriptors,** *Nat. Bur. Stand. (U.S.), Spec. Publ. 327, 235 pages (June 1970) $4.00, SD Catalog No. C13.10:327.*

Key words: Binary liquid mixtures; critical opalescence; critical phenomena; critical point; critical region; equilibrium critical phenomena; gases; liquid-vapor systems; liquids; phase transitions; ternary liquid mixtures; thermodynamics.

This bibliography of 1088 citations comprehensively covers relevant research conducted throughout the world between January 1, 1950 through December 31, 1967. Each entry is characterized by specific key word descriptors, of which there are approximately 1500, and is indexed both by subject and by author. In the case of foreign language publications, effort was made to find translations which are also cited.

Milligan, D. E., Jacox, M. E., Guillory, W. A., **Infrared spectrum of $NO_2$-ion isolated in an argon matrix,** *J. Chem. Phys.* **52,** *No. 8, 3864–3868 (April 15, 1970).*

Key words: Alkali metal atoms; electron bombardment; infrared spectrum; matrix isolation; nitrite anion; nitrogen dioxide; photodetachment; photoionization; vacuum-ultraviolet photolysis.

The molecular ion $NO_2^-$ has been stabilized in an argon matrix in sufficient concentration for detection of its antisymmetric stretching fundamental $\nu_3$, at 1244 $cm^{-1}$ upon electron bombardment or photoionization of matrix-isolated $NO_2$ and by the interaction of an alkali metal atomic beam with $NO_2$ in an argon matrix. In contrast to the position of this fundamental in an inert, non-ionic environment, a value of approximately 1275 $cm^{-1}$ is characteristic of the crystalline material. Isotopic data are consistent with a 155° valence angle for $NO_2^-$ independent of environment. Irradiation of the sample with light of wavelength near 3150 Å leads to the destruction of the $NO_2^-$ absorption in the studies of the electron bombardment and photoionization of $NO_2$, but not in the experiments in which the alkali metal atoms provide a reservoir of photoelectrons.

Mountain, R. D., **Comments on fluctuation theory calculations of the specific heat near the critical point,** *J. Chem. Phys.* **52,** *No. 7, 3852–3853 (Apr. 1, 1970).*

Key words: Cell model; correlation functions of fluids in the critical region; critical phenomena; distribution function; fluctuations in density; specific heat.

The failure of cell model calculations to correctly predict the critical region specific heat anomaly of a fluid is examined. The Gaussian assumption common to these calculations is seen to be the reason for the failure.

Nargolwalla, S. S., LaFleur, P. D., **Characterization of standard reference materials for industry and research by neutron activation analysis,** *Proc. American Nuclear Society Topical Meeting, San Juan, Puerto Rico, May 4–6, 1969, pp. 183–186 (1969).*

Key words: Neutron generator activation analysis; organometallics; oxygen; standard reference materials; steels.

Described herein are examples which demonstrate the use of a low-cost neutron generator facility for materials characterization in the steel and oil industries. Analytical results for oxygen in steels and for the metallic component in a number of organometallic oil additives are given. The accuracy of these results is indicated by the close agreement of the activation data with that obtained by conventional and well proven chemical methods. These applications illustrate the utilization of small accelerators as reliable analytical tools for certification of standard materials useful for industrial and research needs.

Osgood, C. F., **A method in diophantine approximation (III),** *Acta Arithmetica XVI, 5–22 (1969).*

Key words: Algebraic numbers; convolution product; differential equation; diophantine approximation.

In this paper the class of functions discussed in Part II is investigated further. After introducing several normalizing conditions, it is shown to be a module under convolution multiplication from a certain ring of functions. Also algebraic coefficients and algebraic points can now be handled in our original type of differential equation (see (1) on p. 1).

Osgood, C. F., **A method in diophantine approximation (IV),** *Acta Arithmetica* **XVI,** *23–40 (1969).*

Key words: Convolution product; differential equations; diophantine approximation; irrational numbers; $n$-complex variables; rational numbers.

This paper generalizes the results in part III of this series of papers to $n > 1$ complex variables. It is shown that the values of a certain class of functions of $n$ variables are poorly approximable at rational points in an appropriate domain. The algebraic structure of this class of functions is studied in an effort to determine the composition of the class. A module structure is exhibited under convolution product, i.e.

$$g_1(z_1, \ldots, z_n) * g_2(z_1, \ldots, z_n) = \int_0^{z_k} g_1(z_1, \ldots, z_{k-1},$$

$$t_k, z_{k+1}, \ldots, z_n) g_2(z_1, \ldots, z_{k-1}, z_k - t_k, z_{k+1}, \ldots, z_n) \delta t.$$

Parke, W. C., Ponzini, R. G., Williams, H. T., **Remarks on finite-energy sum rules,** *Phys. Rev.* **1,** *No. 1–D, 134–139 (Jan. 1, 1970).*

Key words: Charge exchange; dispersion relations; duality; elementary particles; FESR; high energy scattering; pion-nucleon scattering; regge parameters; sum rules.

Finite energy sum rules with generalized weight functions are discussed with emphasis on methods for obtaining precise determination of high energy parameters from low energy data. Regge parameters for $t = 0$ $\pi N$ charge exchange amplitudes are deduced as an example from a new sum rule.

Paulsen, P. J., Alvarez, R., Mueller, C. W., **Spark source mass spectrographic analysis of ingot iron for silver, copper, molybdenum and nickel by isotope dilution and for cobalt by an internal standard technique,** *Anal. Chem.* **42,** *673–675 (May 1970).*

Key words: Ingot iron; isotope dilution; NBS standard reference material; preconcentration; spark source mass spectrometry; trace element.

Isotope dilution procedures using the spark source mass spectrograph have proven reliable for simultaneous trace element determinations in high-purity metals. The objective of this study was to extend the applicability of this method for determining trace and minor elements in a relatively impure matrix, ingot iron.
In the method developed, isotopically enriched spikes of Ag, Cu, Mo, and Ni were added to 100-mg samples being dissolved; and a known amount of mononuclidic Co was added to half of the samples. After extracting the iron with isopropyl ether, the elements in the aqueous layer were electrodeposited onto gold wire electrodes for sparking in the mass spectrograph. The Ag, Cu, Mo, and Ni concentrations were calculated after determining the altered isotope ratios for all samples. By using Ni as an internal standard and the known additions of Co, the Co concentration was obtained by measuring the Co to Ni ratios for each of the samples. Concentrations ranged from 0.0050% for Ag to 0.025% for Ni.

Penner, S., **Beam handling techniques for electron linear accelerators,** *Nat. Bur. Stand. (U.S.), Tech. Note 522, 21 pages (Apr. 1970), 30 cents, SD Catalog No. C13.46:522.*

Key words: Beam handling; beam optics; beam transport; electron linear accelerator; instrumentation for electron beams; linac.

The design of beam transport systems for electron linear accelerators intended for nuclear physics research is discussed. The subjects covered include beam optics, diagnostics and control of electron beams, and problems of handling high power beams.

Plummer, E. W., Young, R. D., **Field-emission studies of electronic energy levels of adsorbed atoms,** *Phys. Rev. B,* **1,** *No. 5, 2088–2109 (Mar. 1, 1970).*

Key words: Adsorption; alkaline earths; atomic energy levels; surface; tungsten; tunneling resonance.

The relative changes in the total energy distribution of field emitted electrons upon adsorption of single atoms have been measured for adsorption of the alkaline earth atoms (Ba, Sr and Ca) on several crystal planes of tungsten. The expected perturbations of the energy distribution due to the tunneling resonance through an atomic "virtual level" at various positions relative to the Fermi surface and of various half widths $\Gamma$ is demonstrated by a simple one-dimensional calculation. The measured energy dependent structure in the current enhancement factor due to the absorbate has been interpreted in a tunneling resonance model to yield the position and shapes of the atomic "virtual levels." The ground state $^1S6s^2$ level of Ba is broadened to a half width $\Gamma_S = .75$ eV and shifted upward by $\Delta E^S = .95$ eV. This causes it to overlap and mix with the first two excited states: a triplet $^3D$ 6$s$5$d$ and a singlet $^1D$ 6$s$5$d$. The observed $^3D$ and $^1D$ levels were not shifted and had a half width $\Gamma_D = .1$ eV. Similarly the first excited state of Ca, a triplet $^3P$ 4$s$4$p$, was shifted by $\Delta E_{^3P} \approx .4$ eV with a width $\Gamma_{^3P} \approx .3$. The effect of the band structure of the substrate on tunneling resonance is discussed.

Powell, F. X., Johnson, D. R., **Microwave detection of $H_2{}^{18}O$,** *Phys. Rev. Letters* **24,** *No. 12, 637 (Mar. 23, 1970).*

Key words: Astrophysical; emission; galactic distribution of isotopes; $H_2{}^{18}O$; microwave absorption; rotational transition.

Laboratory detection of a microwave absorption in $H_2{}^{18}O$ near 5.33 cm is reported. This observed signal has been assigned to a pure rotational transition between the $6_{16}$ and $5_{23}$ levels in the ground vibrational state of $H_2{}^{18}O$. Signals from these same two rotational levels for $H_2{}^{16}O$ have been detected in emission from several sources in the galaxy.

Qureshi, I. H., McClendon, L. T., LaFleur, P. D., **Extraction studies of the group IIIB–VIIB elements and the lanthanides utilizing *bis*(2-ethyl-hexyl) orthophosphoric acid,** *Radiochim. Acta,* **12,** *No. 2, 107–111 (Aug. 1969).*

Key words: Group VIII; HDEHP; hydrochloric acid; nitric acid; IB and IIB elements; perchloric acid; solvent extraction.

The extraction behavior of the group VIII, IB and IIB elements has been studied from 1$M$–11$M$ hydrochloric, perchloric and nitric acid solutions into 0.75$M$ *bis*(2-ethyl-hexyl) orthophosphoric acid. Cobalt, nickel, copper, zinc, rhodium, silver, cadmium and iridium do not extract while iron is quantitatively extracted from strong nitric acid solutions.

Raveche, H. J., Mayer, J. E., **Theory of diffusion in simple liquid mixtures,** *J. Chem. Phys.* **52,** *No. 8, 3990–4004 (Apr. 15, 1970).*

Key words: Binary liquid mixture; closure condition; diffusion coefficient; distribution function; liquids; reduced Liouville Equations.

A method is presented for obtaining the diffusion coefficient in terms of functions of molecular properties for a liquid system of monatomic molecules near equilibrium. The approach considers the reduced probability density functions $W_n(r_1 \ldots p_n)$ for $n$ molecules $n=1$, 2 and 3, in the limit of a steady state. By operating on the complete probability density function $W_n$ with the conventional Liouville operator and by integrating over the phase space of $N-n$ molecules, we write the time dependence of $W_n$ in a form not explicitly involving $W_m$ for $m>n$. The reduced probability densities and the average vector forces are developed as a power series in a small parameter, λ. Starting with singlet functions, isothermal solution at constant pressure, and the corresponding flux of molecules, we determine a singlet momentum dependent force which maintains the flux and gradient stationary in time. The force can only be consistent with a certain class of pair probability functions and we write the required general forms. Repeating the operation we compute the average pair force which maintains the fluid in a steady state. The operation may, in principle, be carried to $W_{n+1}$ for any $n$. From symmetry requirements we obtain a correction to the Kirkwood closure for the nonequilibrium factors in the triplet probability density. The closure fixes the ratio between the assumed density gradient and flux, which leads to the diffusion coefficient in terms of functions of pairs and triples of molecules and the intermolecular potential energy.

Ritter, J. J., Coyle, T. D., **Halogen exchange reaction of diboron tetrahalides,** *J. Chem. Soc. Sec. A, pp. 1303–1304 (1970).*

Key words: Boron; boron subhalides; exchange; halides; halogen; redistribution.

Halogen exchange between $BCl_3$ and $B_2F_4$ at room temperature occurs in such a way as to concentrate chlorine on the diboron fragment and thus provides a convenient procedure for preparation of $B_2Cl_4$ in >80% yield. Halogen exchange between $B_2Cl_4$ and $(CH_3)_2BF$ leads, however, to formation of $B_2F_4$ and $(CH_3)_2BCl$. Infrared and nuclear magnetic resonance spectra indicate the presence of hitherto undetected diboron chlorofluorides in this system and in $B_2F_4-B_2Cl_4$ and $BF_3-B_2Cl_4$ mixtures.

Romanoff, M., **Corrosion evaluation of steel test piles exposed to permafrost soils,** *Proc. National Association of Corrosion Engineers 25th Conf., Houston, Texas, March 10–14, 1969, pp. 6–13 (National Association of Corrosion Engineers, Houston, Tex., 1970).*

Key words: Corrosion; permafrost; pilings; soil corrosion; steel; steel piles; underground.

This paper describes the results of inspections made to investigate the corrosion of steel pilings in permanently forzen soils, and in the active on their layer of soil above the permafrost layer, as part of the joint investigation conducted by the National Bureau of Standards and the U.S. Army office of the Chief Engineers on the corrosion of steel piles in underground environments.
Nine steel test piles exposed in 3 soil sites at the Alaska Field Station of the U.S. Army Cold Regions Research and Engineering Laboratory at Fairbanks, Alaska, were extracted to investigate the extent of corrosion on the piles. The pipe- and H-pile specimens were exposed underground for 6.2 or 11 years in an active horizon, in which the soil thaws and freezes annually to a depth of approximately 5 feet (1.5 m) and in permanently frozen soil beneath the active layer.
The test piles were installed to depths of 21 feet (6.4m) below ground surface by several different methods.
Results of the inspections show that the steel piles are unaffected by corrosion in the permafrost regions, and that there was no evidence of significant corrosion at the ground line, in the active or thaw region, or at the boundary between the thaw and permafrost regions.

Romanoff, M., **Performance of steel pilings in soils,** *Proc. National Assoc. of Corrosion Engineers 25th Conf., Houston, Texas, March 10–14, 1969, pp. 14–22 (National Association of Corrosion Engineers, Houston, Tex. 1970).*

Key words: Corrosion; H-piles; sheet piles; soil corrosion; soils; steel piles; underground.

This paper consists of a summary of the results of inspections made on steel pilings in various underground structures to investigate the extent of corrosion on steel piles after many years of service in underground environments. This is part of an investigation being conducted by the National Bureau of Standards, in cooperation with the U.S. Army Corps of Engineers and the American Iron and Steel Institute.
Since the 1962 publication of the National Bureau of Standards Monograph 58, "Corrosion of Steel Pilings in Soils", additional data have been obtained from inspections of steel H- and sheet-piles which have been exposed underground from 6 to 50 years in 35 structures in a wide variety of soil conditions.
At 18 locations the piles were pulled from the structures for inspection. At 17 locations, where it was not possible to pull the piles without disturbance to the existing structure, test holes were excavated adjacent to the sheet piling to expose at least an 8-ft width of steel on a section of the structure.
The results from the recent inspections are in agreement with, and substantiate, the observations previously made and published in Monograph 58.
The data show that, in general, pilings are not significantly affected by corrosion in undisturbed natural soils, regardless of the type of soil.
Piling exposed to fill soils, above or in the water table zone, appeared to be the most vulnerable to corrosion. However, only moderate corrosion in the form of localized pitting was generally found in these areas.

Schneider, W. E., **A one-solar-constant irradiance standard,** *Appl. Opt.* **9,** *No. 6, 1410–1418 (June 1970).*

Key words: Calibration techniques; radiometric standards; solar constant; spectral irradiance; total irradiance.

A new high-intensity standard of total and spectral irradiance has been developed recently at the National Bureau of Standards. The standard consists of a 1000-watt tungsten-halogen lamp mounted in a ceramic reflector, the reflecting surface of which is coated with flame-sprayed $Al_2O_3$. The lamp-reflector combination results in a source having a relatively small (3 cm × 5 cm) radiating area yielding a total irradiance, at a distance of 40 cm, of about 136 mW $cm^{-2}$. The total irradiance calibrations are based on the radiance of a 1400 K blackbody and have an estimated maximum systematic error of 0.9 percent and a maximum estimated standard error of 0.19%. The spectral measurements were made over the wavelength region of 0.3 μm to 2.5 μm relative to the NBS 1000-watt tungsten-halogen irradiance standards. The uncertainty in these measurements ranges from 5 percent in the visible and near infrared to 8 percent in the ultraviolet.

Schwerdtfeger, W. J., **Corrosion rates of metals, alloys, and galvanic couples as measured by polarization techniques,** *Mater. Res. Std.* **10,** *No. 3, 22–28 (Mar. 1970).*

Key words: Bridge circuit; change of pH; eight loss; instantaneous corrosion rates; Pearson equation; pit depth; recorder; Stern-Geary equation; synthetic sea water.

A variety of metals and alloys were exposed in the laboratory for 9 months to 340 gal. of synthetic sea water. Corrosion currents calculated from polarization data obtained at periodic intervals were converted to weight losses by Faraday's law. The calculated weight losses were in reasonable agreement with the actual weight losses. Two techniques were used in calculating corrosion currents, namely, the Pearson method, based on breaks in polarization curves, and the Stern-Geary method based on polarization resistances. The two techniques are considered to be complementary. The specimens, after cleaning and evaluation, were reexposed to fresh synthetic sea water. The same polarization techniques were used to measure corrosion rates upon changing the pH periodically from the normal value of 8.5 to 7.1, 5.6 and 4.2 and at pH 4.2 to note the effect on corrosion of water movement produced by compressed air. Finally, it was observed that galvanic corrosion could be measured by the Pearson method when iron was coupled with other specimens which were cathodic. The water was always at room temperature, 70–80 °F (21–27 °C).

Shipp, W. E., **Surface tension of binary mixtures of several organic liquids at 25 °C,** *J. Chem. Eng. Data* **15,** *No. 2, 308–311 (Apr. 1970).*

Key words: Binary mixtures; density; surface tension; organic liquids.

The surface tension was determined for the following pairs of organic liquid mixtures over the entire range of concentration by the differential capillary rise method: Benzene and ethyl acetate, carbon tetrachloride and ethyl acetate, benzene and carbon bisulfide, benzene and carbon tetrachloride, and benzene and acetone. The density of the first three pairs was also measured. Both surface tension and density were measured at 25 °C.

Smith, S. J., **Survey on electron-atom collision experiments** *(Proc. Sommerfeld Centennial Memorial Meeting, Munich, Germany, Sept. 9–14, 1968). Chapter in Physics of the One-and Two-Electron Atoms, F. Bopp and H. Kleinpoppen, Ed., pp. 574–597 (North Holland Publ. Co., Amsterdam, The Netherlands, 1969).*

Key words: Atom; collisions; electron; helium; hydrogen; survey.

Within the last decade, application of the high-vacuum crossed-beam method to low energy collisions of electrons with hydrogen atoms has provided data on elastic, inelastic, and ionizing collisions. The experimental data appear to be largely internally consistent and to provide quite useful comparisons with theoretical results.
In helium, experimental elastic scattering and ionization data appears to be in a reasonable state, but the data on inelastic collisions are generally unsatisfactory. Opportunities for improvement through improved technique are noted.

Snelleman, W., **The measurement and calculation of flame temperatures,** *Chapter 7 in Flame Emission and Atomic Absorption Spectrometry I, 213–239 (Marcel Dekker, Inc., New York, N.Y., 1969).*

Key words: Equilibrium; flame-calculations; flame-composition; flame temperature; line-reversal.

The concept of thermo-dynamic equilibrium and temperature is briefly described and the deviations from this equilibrium that occur in actual flame gases are discussed. The various methods of measuring flame temperatures are considered, with special attention to the method of line-reversal as to systematic and random errors. Next a description is given of the calculation of flame temperatures (with some examples) and finally a comparison is made between calculated and measured flame temperatures.

Stevens, M. E., **Research and development in the computer and information sciences. 2. Processing, storage, and output requirements in information processing systems: A selective literature review,** *Nat. Bur. Stand. (U.S.) Monogr. 113 Vol. 2, 125 pages (May 1970), $1.25, SD Catalog No. C13.44:113/Vol. 2.*

Key words: Computer-assisted-instruction; information display; information recording; machine-aided design; memory allocation; microforms; multiple-access systems; on-line systems; output modes; photocomposition and typesetting; storage hierarchies; time sharing.

Areas of concern with respect to processing, storage, and output requirements of a generalized information processing system are considered. Special emphasis is placed on multiple-access systems. Problems of system management and control are discussed, including hierarchies of storage levels. Facsimile, digital, and mass random access storage media and techniques are considered. A variety of output mode requirements are also considered, including direct recording to microforms; on-line display systems; printing, photocomposition, and automatic character generation; and three-dimensional, color, and other special-purpose display systems. Problems of system use and evaluation are also briefly noted. A bibliography of approximately 480 cited references is included, together with supplemental notes and quotations from the literature.

Swiggard, E. M., Calbaugh, W. S., **Preparation of barium titanate semiconductors containing controlled amounts of neodymium,** *Am. Ceram. Soc. Bull.* **45,** *No. 9, 777–781 (Sept. 1966).*

Key words: Barium titanate; barium titanyl oxalate; neodymium; rare earths; semiconductors.

A procedure is described for coprecipitating known amounts of neodymium with barium titanyl oxalate tetrahydrate. Semiconductors prepared from this doped barium titanate are shown to have predictable electrical properties. Curves and tables show the effect that various conditions have upon the amount of neodymium that is coprecipitated. Curves and tables are also given which show that the electrical properties depend not only on the amount of neodymium present but also on how the neodymium was precipitated with the barium titanyl oxalate. In addition, curves are presented that demonstrate that the firing cycle affects the electrical properties. A method is described for determining the amount of rare earth present in barium titanate.

Thurber, W. R., **Determination of oxygen concentration in silicon and germanium by infrared absorption,** *Nat. Bur. Stand. (U.S.), Tech. Note 529, 21 pages (May 1970) 30 cents, SD Catalog No. C13.46:529.*

Key words: Absorption coefficient; germanium; infrared absorption; methods of measurement; oxygen in germanium; oxygen in silicon; silicon.

Infrared absorption measurements were made at room temperature, 80 K, and 20 K to determine the absorption coefficient of oxygen in silicon and germanium single crystals. A study was done to compare the results of four experimental methods, which involved both absolute and difference procedures. Sources of error were identified, including that due to calculating the absorption coefficient with an approximate equation which neglects multiple internal reflections. Measurements made on the same specimen at several temperatures give additional data on the relation of oxygen concentration to absorption coefficient at low temperatures.

Venable, W. H., Jr., **Effects upon radiant intensity measurements due to scattering by optical elements,** *Appl. Opt.* **9,** *No. 3, 609–615 (Mar. 1970).*

Key words: Instrument function; iterated computation; nitrogen arc; radiance; radiant sources; scattering.

Measurements to determine the radiance of one portion of a nonuniform source can be strongly influenced by radiation from other portions of the source scattered by the optical system used to transmit the radiation to the detector. Conditions under which such scattering is important and procedures to correct for it are discussed. An illustration is provided from measurements made on a nitrogen arc source.

Vicentini-Missoni, M., Joseph, R. I., Green, M. S., Sengers, J. M. H. L., **Scaled equation of state and critical exponents in magnets and fluids,** *Phys. Rev. B,* **1,** *No. 5, 2312–2331 (Mar. 1, 1970).*

Key words: Critical exponents; critical point fluids; curie point; equation of state; ferromagnets; scaling laws.

A systematic analysis in the context of the scaled equation of state has been made of available experimental data in the critical region of a number of ferromagnets [Gd, $CrBr_3$, $La_{0.5}Sr_{0.5}CoO_3$, Ni (two independent sets of data)] and fluids [$CO_2$, $He^4$, Xe] with the following assumed form for $h(x) = HM^{-1} \mid M \mid^{1-\delta}$:

$$h(x) = E_1\left(\frac{x+x_0}{x_0}\right)\left[1+E_2\left(\frac{x+x_0}{x_0}\right)\right]^{2\beta[\beta(\delta-1)-1]/2\beta}$$

$$x = t \mid M \mid^{-1/\beta},\ t = (T-T_c)/T_c,\ \text{and}\ x = -x_0$$

is the phase boundary. A nonlinear, least squares method was used to simultaneously determine the six parameters ($\beta$, $\delta$, $T_c$, $x_0$, $E_1$, $E_2$). Agreement between the proposed form for $h(x)$ and the experimental data was found. For both the magnets and fluids we find that $\delta \approx 4.4$; for the magnets $\beta \approx 0.37$ and for the fluids $\beta \approx 0.35$. Reasons for the considerably different values reported elsewhere for these exponents in the materials $CrO_2$ and $YFeO_3$ are discussed.

Vidal, C. R., Cooper, J., Smith, E. W., **Hydrogen stark broadening calculations with the unified classical path theory,** *Nat. Bur. Stand. (U.S.), Monogr. 116, 143 pages (May 1970) $1.50, SD Cagalog No. C13.44:116.*

Key words: Classical path; hydrogen lines; line wings; one-electron theory; Stark broadening; unified theory.

The unified theory has been generalized for the case of upper and lower state interaction by introducing a more compact tetradic notation. The general result is then applied to the Stark broadening of hydrogen. The thermal average of the time development operator for upper and lower state interaction is presented. Except for the time ordering it contains the effect of finite interaction time between the radiator and perturbers to all orders, thus avoiding a Lewis type cutoff. A simple technique for evaluating the Fourier transform of the thermal average has been developed. The final calculations based on the unified theory and on the one-electron theory are compared with measurements in the high and low electron density regime. The unified theory calculations cover the entire line profile from the line center to the static wing and the simpler one-electron theory calculations provide the line intensities only in the line wings.

Weiss, A. W., Krauss, M., **Bound-state calculation of scattering resonance energies,** *J. Chem. Phys.* **52,** *No. 9, 4363–4368 (May 1, 1970).*

Key words: Ar; correlation energy; Feshbach resonance state; Hartree-Fock; He Ne; HF $H_2O$; $N_2$; resonance energy; Rydberg; valence.

Resonance energies in electron scattering are estimated by calculating bound trial functions which represent electron attachment to the lowest Rydberg state. The trial functions are kept orthonormal to a single-configuration description of the target state and so represent an approximation to the Feshbach procedure. Correlated trial functions are used for $He^-(^2S)$, $Ne^-(^2P)$, and $Ar^-(^2P)$. The resonant energy predictions are in good agreement with observation. In addition, the correlation energy for the $ns^2$ pairs range from 0.55 to 0.75 eV. These correlation energies are used to correct Hartree-Fock estimates of resonance energies computed for the HF, $H_2O$, and $N_2$ molecules. Energy curves obtained for $HF^-(^2\Pi)$ indicate a dissociative attachment process is possible that leads to production of the $H^-$ ion. Only single points are calculated for $H_2O$ but the $^2B_1$ resonance state is assigned to a dissociative attachment at 6.5 eV incident electron energy that yields the $H^-$ ion. In addition to the attachment to Rydberg excited states, two $N_2$ valence-type Feshbach states are calculated. The results for $\sigma_g\Pi_g^2$, $^4\sum_g^-$ and $^2\Delta_g$, when used with correlation energy estimates lead to the conclusion that valence-type Feshbach states are not bound relative to their concomitant neutral excited valence state. Sharp resonances would not then be expected below such neutral states.

Wells, J. S., Evenson, K. M., **A new LEPR spectrometer,** *Rev. Sci. Instr.* **41,** *No. 2, 226–227 (Feb. 1970).*

Key words: Laser electron paramagnetic resonance spectrometer; oxygen.

A new spectrometer for conducting laser electron paramagnetic resonance experiments on gases is described. This spectrometer yields at least an order of magnitude better sensitivity than the first spectrometer used in this type of investigation.

West, E. D., Jennings, D. A., **Power measurement of large laser beams with a small dual-cone calorimeter,** *Rev. Sci. Instr.* **41,** *No. 1, 142 (Jan. 1970).*

Key words: Calorimeter; laser; laser calorimeter; laser energy; laser power.

Measurements of power and energy in large laser beams can be made with a small dual-cone calorimeter by covering the entire front surface with an aperature for the input cone. Irradiating only part of the front surface gives an error in the measurement.

Wilson, W. K., **Record papers and their preservation,** *Chemistry* **43,** *No. 3, 8–12 (Mar. 1970).*

Key words: Degradation; paper; preservation of records; records; stability.

Variables in the papermaking process are discussed in relation to the stability of the finished product. Restoration methods, storage of records, and current research on preservation of records are described.

Zielinzki, W. L., Freeman, D. H., Martire, D. E., Chow, L. C., **Gas chromatography and thermodynamics of divinylbenzene separations on 4,4′-dihexoxyazoxybenzene liquid crystal,** *Anal. Chem.* **42,** *No. 2, 176–180 (Feb. 1970).*

Key words: Chromatography; divinylbenzene; gas-liquid chromatography; liquid crystal.

Gas-liquid chromatography in the nematic liquid region of 4,4′-dihexoxyazoxybenzene has shown base-line separations for the meta and para isomers of divinylbenzene and ethylvinylbenzene. Thermodynamic treatment of the data has illustrated that the meta isomers have lower solubility than the respective para derivatives owing to a greater enthalpic requirement for solution in a rod-like solvent. The para/meta separation factors depict a greater rate of decrease with increasing column temperature in the isotropic liquid phase due to the loss of order which is present in the anisotropic nematic region. Data from naphthalene, present as a contaminant in divinylbenzene samples, were included in the treatment. Chromatographic extension to preparative scale appears feasible.

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